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PRODUCTION OF GATEWAY BARLEY AS INFLUENCED BY FERTILIZER, SOIL TEST LEVELS AND MOISTURE STRESS

by

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B.Sc.

A THESIS

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The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance a thesis entitled "Production of Gateway Barley as Influenced by Fertilizer, Soil Test Levels and Moisture Stress" submitted by Leonard Angus Heapy, B.Sc., in partial fulfilment of the requirements for a degree of Doctor of Philosophy.

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ABSTRACT

Multiple regression analysis was used to relate yield of Gateway barley, grown under dryland conditions in central Alberta, to certain controlled and uncontrolled variables. The controlled variables were rates of applied nitrogen and phosphorus fertilizers. The uncontrolled variables were soil test levels of nitrate-nitrogen and available phosphorus and moisture stress occurring prior to heading of the crop. Pooled data of 17 site-years were used to derive a barley yield equation which explained 55 per cent of yield variation occurring on three Chernozemic and three Luvisolic soils.

External data were used to establish a suitable moisture stress criterion and to evaluate the effect of moisture stress on yield of barley. This analysis involved the calculation of a daily soil moisture budget for each experimental site and a count of days of moisture stress based on this budget. The growing period was divided into seven intervals, representing stages of crop development. Yield of barley was regressed on stress ratios (count of stress days/ total days in interval) occurring within the seven intervals. In this regression yield of barley was an average site yield over plots where nutrients were not limiting. This analysis carried out on external data provided a method for calculating a moisture stress index for each of the 17 site-years.

The derived yield equation was used to examine several aspects of fertilizer use in cereal production. The results indicate the following. (a) The optimal inputs of nitrogen are substantially

lower when soil moisture conditions are poor than when they are good at time of seeding. (b) The ratio of nitrogen to phosphorus recommended at optimal input rates is unlikely to be the least-cost combination of fertilizer inputs at rates less than optimal. (c) The influence of soil nitrate-nitrogen, evaluated to a depth of 61 cm, on the nitrogen fertilizer requirement was less than the interpretation made by the provincial soil testing service. At low levels of soil nitrogen there was good agreement with the soil testing service but at moderate soil test levels the nitrogen calculated inputs were about 40 per cent higher than those presently recommended. (d) The optimal inputs of phosphorus fertilizer were about 30 per cent lower than those recommended by the soil testing service. (e) Response patterns to nitrogen and phosphorus fertilizers were similar for Chernozemic and Luvisolic soils in central Alberta, supporting the interpretation now made by the provincial soil testing service.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

INTRODUCTION

Multiple regression analysis is used to interpret the results of a field investigation into the use of fertilizers in barley production. Yield equations are derived, relating barley yield to:

(a) rates of applied nitrogen and phosphorus fertilizers,

(b) soil moisture conditions over the growing season and

(c) soil test levels of nitrate-nitrogen and available phosphorus.

In the semi-arid environment of the Prairie Provinces of Canada, yield and response to fertilizers of cereal crops grown under dryland conditions are largely influenced by the amount and distribution of seasonal rainfall. A soil moisture term in the yield equations is directed to the problem of collating evidence of fertilizer response obtained from sites subjected to different soil moisture regimes. The immediate application of improved soil test interpretation is evident from the call on the provincial soil testing service to provide fertilizer recommendations for the 1968 season to about 5,000 Alberta farmers.

The data for this study were obtained from an interdisciplinary research project which had the following specific objectives:

(a) to derive yield equations relating yields of cereal and forage crops to a number of independent variables including available nutrients in the soil, fertilizer nutrients and certain environmental factors,

(b) to determine the optimum rates of fertilization, using the derived yield equations and

(c) to evaluate the effects of the variables on crop quality.

Field experiments were conducted at six locations in central Alberta, three within 30 kilometers of Edmonton and three within 50 kilometers of Lacombe. Sites, three on Chernozemic and three on Luvisolic soils, were selected in consultation with personnel of the Alberta Soil Survey, a major consideration being that each site should be located upon a member of a soil grouping of significant agricultural importance. Important features of the experimental plan were:

(a) A set of barley plots was laid out at each location. One crop of barley was produced annually on each set.

(b) The response of barley to N, P and K fertilizers was studied. Two replications of a 5^3 central composite design was used, involving 23 treatments. A fertilizer treatment, applied annually at time of seeding, was assigned to each plot.

(c) In the spring and fall, prior to seeding and after harvesting, soil samples were collected from each plot for moisture analysis and soil testing.

(d) Certain daily meteorological observations, including rainfall, were recorded at each site. Stages of development of the barley crop were followed by regular visits to the sites.

Commenced in 1964, this phase of the barley project terminated in 1968 after twenty-six site-years had been set out. In 1969 a study commenced at all six barley sites into the residual effects of the fertilizer treatments, barley remaining as the test crop.

The hazards of field experimentation took a heavy toll as nine of the twenty-six site-years had to be discarded, leaving only seventeen

for this study. The greatest loss occurred in 1968 when all six sites had to be discarded because abundant late tillers were unable to ripen after smothering a light, earlier crop of barley.

This presentation is the first formal report on results of the project. The objectives of this phase of the project were:

(a) To determine the response of barley to nitrogen, phosphorus and potassium fertilizers on certain soils in central Alberta.

(b) To develop a method for assessing the effect of soil moisture stress on yield and response to fertilizers of barley grown under dryland conditions.

(c) To develop a methodology for determining the optimum rates of applied fertilizers for barley grown on stubble when soil test data are available.

(d) To derive a generalized yield equation relating yield of barley grown on stubble to rates of applied fertilizers, soil test levels, moisture stress and soil grouping.

REVIEW OF LITERATURE

A. Fertilizer investigations in the Prairie Provinces

Investigations into the response of various crops to fertilizers have long been an integral part of agricultural research in the three Prairie Provinces of Canada. Trials at the Dominion Experimental Farms, reviewed by Hopkins and Leahey (1944), failed to show appreciable yield increases until about 1928 when the practice of broadcasting the fertilizer was replaced by the combination grain and fertilizer drill. These early studies demonstrated the importance of the amount and distribution of seasonal rainfall to fertilizer response.

In 1928 extensive fertilizer trials were undertaken with the aid of co-operating farmers. Trials in Alberta in 1930, summarized by Wyatt *et al.* (1939), demonstrated a definite response of cereals to ammonium phosphate and triple superphosphate for the Brown and Black soils. Mitchell (1932) reported some very marked responses of wheat grown on summerfallow soils in Saskatchewan to triple superhosphate and Ellis (1934) reported a response to nitrogen and phosphorus fertilizers and a general lack of response to potassium fertilizer for wheat on Manitoba soils. From the evidence of subsequent trials, a project which avoided the drier Brown soil zone, Mitchell (1946) recommended for wheat grown on summerfallow in Saskatchewan applications of 11-48-0 at rates of 20 to 40 pounds per acre.

In Alberta attention was also given to the role of fertilizers in the management of Gray Wooded soils. Co-operative fertilizer trials on these soils commenced in 1929 and the Breton experimental plots were

set out in 1930. From initial observations made on the Breton plots, Newton (1936) reported sulphur deficiency of some Gray Wooded soils for legume production. Reviewing the first fifteen years of this study, Wyatt (1945) remarked that with proper management, which included the use of fertilizers, the productivity of the Gray Wooded soils compares favourably to that of the Black soils in Alberta.

The Alberta Department of Agriculture (1968) published general fertilizer recommendations for crops grown in central and northern Alberta. Nitrogen and phosphorus are usually deficient for all crops. A response to potassium is noted for potatoes grown on light-textured, moderately calcareous soils. Some Dark Gray Wooded and Gray Wooded soils are sulphur deficient for legume production and the farmer is advised to set out test strips to check his fields for sulphur deficiency. Nyborg (1968) reported sulphur deficiency for oat production at four sites on different Gray Wooded soil series in the Peace River region. Campbell and Skoropad (1961) confirmed manganese deficiency as the cause of "grey speck" of oats, first observed at Edmonton in 1956. This disease of oats is sporadically distributed throughout northern Alberta, generally associated with high organic matter content of the soil, or high soil pH, or both. Foliar spraying with manganese sulphate has proven successful in treatment of the disease.

The Alberta Department of Agriculture established the Alberta Soil Testing Laboratory in 1955. Some of the problems encountered by the soil testing service are pertinent to this investigation and, excluding the interpretation of soil test data, are reviewed at this time as they relate to field investigations into the use of fertilizers.

Collection of soil samples. In Alberta the soil test sample is collected to a depth of six inches (15.2 cm) and the farmer is provided with instructions for obtaining a representative sample (or samples) from the field. Rennie and Clayton (1960) demonstrated the variability in yield and response to phosphorus that can be expected within relatively short distances in any one field in which complexity of soil pattern occurs. Such complexity of soil would be a problem in deciding upon the appropriate fertilizer input, but the farmer can be expected to be aware of significant changes of soil pattern within a field and he has the option to select practical, but less heterogeneous, sampling units.

The six-inch sampling depth, while convenient in meeting the need for a representative sample, is possibly too shallow for defining the nitrogen requirement. In Manitoba, where the nitrogen requirement is assessed by sampling to a depth of twenty-four inches, Soper and Huang (1963) found that the nitrate-N content of the soil to a depth of forty-eight inches (122 cm) gave the best correlation with yield response to nitrogen fertilizer.

Nitrogen requirement. In Alberta the nitrogen requirement is based on a nitrate-N soil test, modified by crop to be grown and cropping history of the field. Perhaps the potential of the soil to mineralize organic forms of nitrogen should be considered, as shown by the studies of Synghal *et al.* (1959), Smith (1966) and Geist *et al.* (1970). However the studies of Wyatt *et al.* (1927) indicate that this potential may not be realized under field conditions, as soil moisture conditions, the

growing crop, the cropping sequence, method of cultivation and soil temperature can influence the process of mineralization of organic-N.

Phosphorus requirement. Most soils in the Prairie Provinces require added phosphorus for adequate crop production. Mitchell (1932) demonstrated the usefulness of a soil test method based on acid extraction in predicting the phosphorus fertilizer requirement of Saskatchewan soils for wheat production. The provincial soil testing services in Manitoba, Saskatchewan and Alberta use different extraction procedures as a soil test for "available" soil phosphorus. The acid extraction procedure used in Alberta, described later in the text, was compared to an alkaline procedure by Robertson (1962) and both procedures yielded very similar information on 79 Alberta soils.

The predictive value of the phosphorus soil test for Alberta soils is far from perfect and the empirical nature of extraction methods is a weakness in the interpretation of observed discrepancies in response to added phosphorus. Recent studies, by Nyborg and Hennig (1969) on different placements of fertilizers for several field crops, by Omanwar and Robertson (1970) on the process of P movement to roots and by Alexander (1967) on inorganic phosphorus forms in Alberta soils, contribute to an understanding of the roles of soil and applied phosphorus in crop production. The rooting habit of the plant is an important factor in the uptake of soil phosphorus; thus for important field crops, an investigation into varietal differences in phosphorus requirement seems desirable.

Potassium requirement. The potassium status of Alberta soils is generally sufficient for crop production. Potassium deficiencies do occur as shown by the studies of Goettel (1962), Nelson (1964) and Tsai (1966). The Alberta soil test method for potassium (extraction by 1.0N ammonium acetate) is described later in the text. The test is not regarded as definitive, rather a test value of 250 lb/a (280 kg/ha), or less, is indicative of a possible soil potassium deficiency.

B. Soil moisture conditions and crop production

Soil moisture reserves and rainfall distribution during the growing season are important factors affecting cereal production in the three Prairie Provinces. Barnes (1924) used lysimeters to study soil moisture under crop and fallow conditions at Swift Current, and observed that fallow tanks were able to conserve 23 per cent of the 20 inches (50.8 cm) of precipitation received during the 12-month period prior to seeding. Hopkins (1935) found a significant correlation between yield of wheat in western Canada and the amount and distribution of seasonal rainfall; the maximum influence appeared to be exerted during the month of June. Lehane and Staple (1965), by multiple regression analysis, found that rainfall received during June and July and available soil moisture stored below the 12-inch (30.5 cm) depth were important factors influencing wheat yields in southwestern Saskatchewan. In wetter seasons, yields were higher on both clay and loam than on sandy loam.

Various workers have investigated the effect of moisture stress on cereal crops. Studies in Alberta of the susceptibility of cereal

varieties to drought at different stages of development have been reported by Aamodt and Johnston (1936) for wheat and by Wells and Dubetz (1966) for barley. Chinoy (1962) studied the physiology of drought resistance in wheat. Aspinall _et al._ (1964) investigated the physiological effects on barley of repeated short cycles, single short cycles and single long cycles of moisture stress. From studies such as these, and the reviews by Henckel (1964) of the physiology of plants under drought conditions and by Slatyer (1967) of the significance of water deficits to physiological processes, certain general statements can be made of the effects of moisture stress on the growing plant:

(a) The organ which is growing most rapidly at the time of a stress is the one most affected.

(b) Tillering, while suppressed by stress, may be stimulated by the stress experience when the stress has been removed.

(c) During the development of reproductive organs, all physiological properties change in the direction of lower resistance to moisture stress.

(d) The effects of stress on yield are greater at the early boot stage than at the soft dough stage and in turn greater than at the onset of tillering or ripening.

While the foregoing generalizations consider the plant in discrete stages of physiological development, doubt was expressed by Bunting and Drennan (1966) as to the reality of the concept of separate vegetative and reproductive phases for the tillering plants.

Lawes and Gilbert (1880) examined the relationship between yields of wheat at Rothamsted and rainfall and commented that the effect

of a climatic event on wheat yield is influenced by the stage of growth of the plant. Numerous workers, especially in regions where the uncertainty of rainfall is a hazard to crop production, have examined this relationship. A linear model is commonly assumed, equating yield of a particular crop to the additive effects of precipitation amounts received within chosen calendar intervals. A more realistic concept of the relationship was developed by Blumenstock (1942) and Barger and Thom (1949) who considered the effect of rainfall on available soil moisture and the occurrence of drought. Subsequently, the "drought criterion" was proposed by van Bavel (1953) to express the physiological role of soil moisture. By this concept, a drought-day is defined as a 24-hour period in which the soil moisture stress exceeds a limit, which on the basis of experimental evidence, may be taken as a point at which the productive processes of the crop are being appreciably decreased.

Parks and Knetsch (1959) applied the drought-day concept in a study of the nitrogen fertilizer requirement for corn production of a soil in Tennessee. In this study a drought index value was obtained by inserting the count of drought-days into an externally-generated equation which weighted the relative importance of a drought condition occurring in four successive periods of corn development. Zahner and Stage (1966) also used the drought-day concept in a study of the influence of weather conditions on tree growth.

An obstacle to the use of the drought-day concept in studies of crop production is the problem of assessing soil moisture conditions over the growing season. However, this obstacle is not too great as techniques have been developed to estimate a soil moisture budget by

various observations on the soil-plant-atmospheric environment. In the calculation of a soil moisture budget a problem commonly encountered is a need to estimate actual upward moisture loss, or evapotranspiration. This problem is usually resolved by first estimating potential evaporation (PE), then evapotranspiration is related to PE as modified by certain soil and plant characteristics. Sellers (1965) described methods of measuring or estimating potential evaporation. Penman (1963) presented arguments for and against some of the "drying curves" that have been proposed to describe availability to the plant of soil water at different soil water potentials.

From the work of Holmes and Robertson (1959), Baier and Robertson (1966) and Baier (1969), a soil moisture budgeting technique was evolved which considers depth of rooting, stage of plant development and permits the selection of a "drying curve" from several options. The methodology developed by Shaw (1963) for estimating soil moisture conditions under corn draws upon the results of prior research by Denmead and Shaw (1959, 1962) to introduce the effects of stage of development of the crop and availability of soil water to the plant.

C. Mathematical models in agricultural research

In the Prairie Provinces of Canada, as in many areas of the world, fertilizers have attained much importance as an input in agricultural production. In Alberta in 1968, investment in fertilizers exceeded $30,000,000, a six-fold increase within one decade. As the nature of this increase in fertilizer usage was influenced by fertilizer recommendations of an advisory service, it is desirable to examine some of the economic aspects of these recommendations. However, this appraisal is most difficult for, as commonly encountered elsewhere, much of the evidence of response to fertilizers does not exist in a mathematical form amenable to economic analysis.

The input-output relationship

A mathematical model is a convenient technique for expressing a concept of the relationship between two or more variables. Several workers, including Heady (1952), Munson and Doll (1959) and Tisdale and Nelson (1966) have sketched the historical development of these models in the agricultural sciences. A feature of these biological models is the need for some simplifying assumptions. Thus, a continuous causal relation between inputs (X_i) and output (Y) is commonly assumed, such that the system can be described by a single equation of the form:

$$Y = f(X_1, X_2, X_3, \ldots, X_n). \tag{1}$$

Heady and Dillon (1961) and Smith (1969) examined various algebraic forms of this model or "yield equation", particularly with regard to the suitability of the form in describing the "law of diminishing

returns". Brownlee (1965) and Draper and Smith (1967) discussed various aspects of the methodology of estimating the parameters of these models by the procedure of least squares or "regression" analysis.

The mathematical analysis of a complex problem can lead logically to a system of simultaneous equations. For example, if a process occurs in discrete stages, then the resultant output can be examined as a function of the intermediate outputs in the chain. Ferrari (1965) disapproved of an unquestioning use of regression models in biological research and applied a set of simultaneous equations to a description of relationships involved in a particular chain process. Heady and Dillon (1961) noted that "single equation estimates have generally been found to be just as logical and meaningful in an economic sense as those derived at much more expense by the use of simultaneous equation models". As understanding of plant processes broadens, more complex models will no doubt become more common in biological research. However, Grodins (1963) found system isolation and "adaptive behaviour" formidable obstacles to building realistic functional models of biological systems.

Some economic considerations

In fertilizer investigations, crop response to a single applied nutrient (X_1) can be examined by a yield equation of the form:

$$Y = f(X_1). \qquad (2)$$

For inputs of two nutrients (X_1) and (X_2) the yield equation may be:

$$Y = f(X_1, X_2) \tag{3}$$

Equation (3) describes a surface in three-dimensional space, with axes X_1, X_2 and Y. In addition to factor-product relations, the three-dimensional equation implies certain factor-factor relations. Two aspects of the factor-factor relations should be noted:

(a) The algebraic form of the yield equation should not constrain the model from describing the actual nature of the response surface. Heady and Dillon (1961, ch. 6) discussed the choice of the algebraic form of the yield equation and noted that a polynomial approximation usually fits the production surface adequately.

(b) Usually fertilizer recommendations are made in the form of rate and formulation. The farmer may decide on a fertilizer investment less than that implied in the recommendation and, unaware of factor-factor relations, simply reduce the rate of fertilizer applied. Heady (1952) discussed principles of resource combination and cost minimization. Least-cost combinations of inputs on the production surface should be carefully examined and the fertilizer recommendation should reflect significant changes in fertilizer formulation (resource combination) as the capital invested in fertilizer increases.

MATERIALS AND METHODS

A. Description of the experimental area

The experimental area is situated in central Alberta, between 52° and 54° N latitude and 113° and 115° W longitude, as shown in Figure 1. The elevation above sea-level increases gradually from north to south, being 670 m at the Edmonton Industrial Airport and 848 m at the Lacombe Research Station.

The climate of the area is continental, with warm summers and cold winters. The prevailing winds during the summer are cool and dry with Maritime Pacific air moderating temperatures such that the highest temperature ever recorded in Edmonton is 99 F (37.2 C). The monthly average values for certain meteorological observations at the Edmonton Industrial Airport are set out in Table 1. The climate is semi-arid, with an annual average precipitation of 48 cm. While 65 per cent of the annual precipitation falls during the growing season, a moisture deficit at critical stages of crop development is usually the greatest hazard to crop production. The variability of precipitation during the summer months of May to September is indicated by data presented in Table 2.

Mixed farming is general in the area, with early-ripening varieties of barley being an important cereal crop. Forage production is substantial and increasing, as a result of changing farm production patterns. The farm operator must contend with high land values and, due to social and economic pressures, increasing labour costs. To meet the problem of labour costs, there is a continuing trend to mechanization

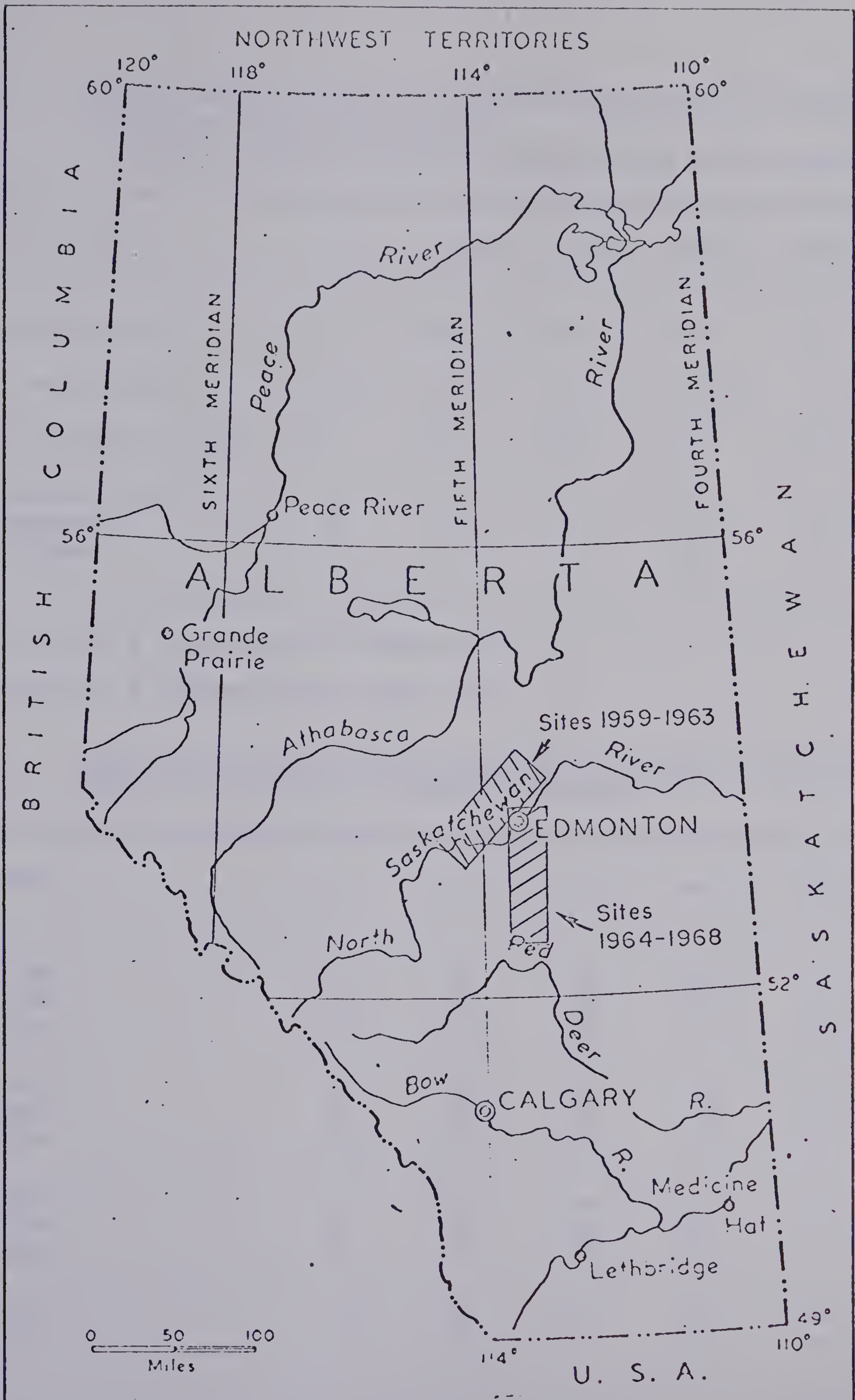


Figure 1. Location of experimental sites.

TABLE 1. Monthly average values of selected meteorological observations at Edmonton Industrial Airport
(Location: 53°35'N,113°30'W. Elevation: 670 m above sea-level)

Observation	May	June	July	Aug.	Sept.
Precipitation, mm[a]	46	81	84	66	36
Wind, km per hour[b]	16.9	16.1	14.3	13.7	15.4
Bright sunshine, hours[a]	267	251	305	268	186
Air temperatures, C[a]					
Maximum	16	20	24	25	22
Minimum	5	9	12	13	9

[a] Based on a 30-year period ending 1960.

[b] Based on a 30-year period ending 1968.

TABLE 2. Total monthly precipitation, mm, May to September inclusive, 1959-1969, at Edmonton Industrial Airport

Year	May	June	July	Aug.	Sept.
1959	19	68	68	98	51
1960	58	73	82	94	61
1961	22	47	95	6	25
1962	52	78	81	57	26
1963	19	55	65	28	33
1964	54	26	75	71	64
1965	72	190	54	54	23
1966	28	23	62	164	9
1967	42	43	51	74	1
1968	3	54	78	85	35
1969	33	25	84	114	80

as a substitute for farm labour. The size of farms varies greatly within the area, with 300 to 400 ha considered viable mixed farming units.

B. Field techniques

Information available from an earlier study into the response of barley to fertilizers is introduced into the analysis in the next section. As this prior study has not been reported elsewhere, field techniques are briefly presented below.

Field investigations, 1959 - 1963

The objective of this previous study was to assess the predictive value of soil test recommendations for nitrogen and phosphorus requirements of barley grown on stubble. Six of thirty-three sites were deleted from the study due to hail damage, excessive weed growth, etc. Names of co-operators, soil series and legal location of sites are presented in Table 3. Classification of the soils is set out in Table 5.

At each site the experimental design was a 5^2 complete factorial, with six replicates. N (as ammonium nitrate) and P_2O_5 (as single superphosphate) were each applied in all combinations of 0, 11.2, 22.4, 44.8 and 89.6 kg/ha. Each site received a blanket application of K (as potassium chloride) at 37.2 kg/ha prior to seeding. Plot size was 1.07 m (6 rows) by 6.10 m. Cultivation prior to seeding was done by the co-operator. The N and P fertilizers were applied at time of

TABLE 3. Site details for field investigations 1959 - 1963

Site-year					Co-operator	Legal location	Soil series[a]
	0160				J. Kobylka	SE-31-50-26-4	Peace Hills
0259	0260				J. Kozial	SE-31-49-27-4	Navarre
0359	0360	0361			A. Sund	SE-31-48-27-4	Angus Ridge
	0460				E. Litzenberger	SE-15-51- 1-5	Codner
	0560	0561	0562	0563	H. Evjen	SW-32-51- 1-5	Winterburn
		0661			W. A. Kreye	NW--2-51- 2-5	Glory
		0761	0762		W. Abramski	NE- 7-57-23-4	Leith
				0763			Culp
		0861	0862	0863	W. Lesyk	SW- 7-56-23-4	Rimbey
		0961				NE-18-56-23-4	Rimbey
			0962		L. Nielsen	SW-20-56-23-4	Rimbey-Ponoka complex
				0963		NW-17-56-23-4	Rimbey-Ponoka complex
		1061	1062	1063	G. Reith	NW- 3-57-24-4	Navarre-Peace Hills complex
			1162	1163	W. V. Christensen	SE-31-51- 1-5	Carvel-Leith complex
			1262		H. Schlecker	NW-15-51- 1-5	Rimbey

[a] Soil classification of series names, see Table 5.

seeding: the N broadcast on the surface, the P placed with the seed. Gateway barley, an early ripening variety, was the test crop. Plots were harvested by cutting a portion from the middle two of the six rows (except in 1963 when four rows were taken due to low yields).

A composite soil sample of five sub-samples was collected at each site prior to seeding. In 1966 several soil sample cores were collected at each site for additional analyses.

Rain gauges were installed at each site. As sites were visited only periodically, a small amount of mineral oil was placed in each gauge to prevent evaporation of collected water. Site visits were infrequent: the first visit would be about two weeks after seeding to observe germination, the second visit about three weeks later to spray weeds and subsequent visits about every third week.

Field investigation, 1964 - 1968

The objectives of this study are set out in the introduction. It will be noted that the objective of the previous project was retained. To accomplish the additional objectives the field techniques were necessarily more elaborate than usually encountered in field investigations into fertilizer response of cereal crops.

Sites. Six barley sites were established, three in the Edmonton area (coded 01, 03, 05) and three in the Lacombe area (coded 21, 23, 25). Sites were selected in consultation with personnel of the Alberta Soil Survey to ensure that each site was located upon a soil grouping of significant agricultural importance. Data collection commenced in 1964 at sites 01 and 21 and in 1965 the other sites were

brought into the study. Names of co-operators, past cropping history, legal location and soil series involved for the six sites are set out in Table 4. Series names are identified within three systems of soil classification in Table 5. Responsibility for supervision of field operation was divided: staff of the Department of Soil Science, University of Alberta managed sites 01, 03 and 05 and staff of the Lacombe Research Station, Canada Department of Agriculture managed sites 21, 23 and 25.

Experimental design. To study the three factors, nitrogen, phosphorus and potassium, each at five levels, a 5^3 partial factorial design was selected[1]; a member of a set known as a central composite design. The geometric pattern of this particular member is compared to that of the complete factorial design:

	Total units	Units retained	Position of units retained
Outer shell	98	8	corners
		6	face-centres
Inner shell	26	8	corners
Centre	1	1	
	125	23	

To round-off the field plan, the check (0-0-0) was duplicated, giving a total of 24 plots in each of the two replicates. Treatment levels for the barley sites and combinations used are set out in Table 6.

[1] Recommended by Dr. J. Pesek, Head, Department of Agronomy, Iowa State University, Ames, Iowa.

TABLE 4. Site details for field investigations 1964 - 1968

Site	Co-operator	Past cropping history[a]	Legal location	Soil series[b]
01	University of Alberta, Ellerslie Farm	1962 - fallow 1963 - barley-grass mixture 1964 - site established	NE-24-51-25-4	Navarre-Malmo complex
03	H. Shewchuk, RR 2, Ardrossan	? - pasture several years, weed species dominant 1965 - site established	SE-28-52-21-4	Cooking Lake
05	V. G. Lawrence, Fort Saskatchewan	1963 - oats (15 q/ha) 1964 - barley-grass-legume 1965 - site established	SE-11-54-22-4	Angus Ridge
21	Lacombe Research Station, Canada Dept. Agr.	1963 - oats for silage 1964 - site established	NE-24-40-27-4	Ponoka
23	G. Goulden, RR 1, Tees	1964 - alfalfa-timothy-brome 1965 - site established	NW-29-41-23-4	Breton
25	P. H. Reed, RR 1, Tees	1964 - barley (N fertilized, about 25 kg/ha) 1965 - site established	NW-21-42-23-4	Breton

[a] Fertilizers not applied unless indicated.

[b] Soil classification of series names, see Table 5.

TABLE 5. Classification of soil series, experimental sites 1959 - 1968

Soil series	Soil classification		
	Canadian system	American system	World system
Navarre, Peace Hills	Orthic Black Chernozem	Typic Cryoboroll	Haplic Chernozem
Angus Ridge, Ponoka, Malmo	Eluviated Black Chernozem	Boralfic Cryoboroll	Luvic Chernozem
Winterburn, Rimbey	Orthic Dark Gray Chernozem	Boralfic Cryoboroll	Luvic Chernozem
Glory, Culp, Cooking Lake, Breton	Orthic Gray Luvisol	Typic Cryoboralf	Albic Luvisol
Leith, Carvel	Dark Gray Luvisol	Typic Cryoboralf	Albic Luvisol
Codner	Orthic Humic Gleysol	Cryaquoll	Humic Gleysol

TABLE 6. Treatment numbers: rates of nitrogen, phosphorus and potassium for field experiments 1964-1968

Treatment number	rate, kg/ha			rate, lb/a			code		
	N	P	K	N	P	K	N	P	K
1	33.6	13.4	13.4	30	12	12	-1	-1	-1
2	33.6	13.4	40.2	30	12	36	-1	-1	+1
3	33.6	40.2	13.4	30	36	12	-1	+1	-1
4	33.6	40.2	40.2	30	36	36	-1	+1	+1
5	100.8	13.4	13.4	90	12	12	+1	-1	-1
6	100.8	13.4	40.2	90	12	36	+1	-1	+1
7	100.8	40.2	13.4	90	36	12	+1	+1	-1
8	100.8	40.2	40.2	90	36	36	+1	+1	+1
9	67.2	26.8	26.8	60	24	24	0	0	0
10	0	26.8	26.8	0	24	24	-2	0	0
11	134.4	26.8	26.8	120	24	24	+2	0	0
12	67.2	0	26.8	60	0	24	0	-2	0
13	67.2	53.6	26.8	60	48	24	0	+2	0
14	67.2	26.8	0	60	24	0	0	0	-2
15	67.2	26.8	53.6	60	24	48	0	0	+2
16	0	0	53.6	0	0	48	-2	-2	+2
17	0	53.6	0	0	48	0	-2	+2	-2
18	0	53.6	53.6	0	48	48	-2	+2	+2
19	134.4	0	0	120	0	0	+2	-2	-2
20	134.4	0	53.6	120	0	48	+2	-2	+2
21	134.4	53.6	0	120	48	0	+2	+2	-2
22	134.4	53.6	53.6	120	48	48	+2	+2	+2
23	0	0	0	0	0	0	-2	-2	-2
24	0	0	0	0	0	0	-2	-2	-2

Plot size. Plot size was decided by the type of seeding equipment. In the Edmonton district plots were 244 x 610 cm, to accommodate two passes of the Allis-Chalmers drill described by Bentley (1956). This 6-row drill gave 17.8 cm spacing between rows. Plot size in the Lacombe district was 183 x 610 cm to accommodate two passes of the "Ridemaster" seeding equipment. This 4-row drill gave 23 cm spacing between rows.

Seed and fertilizer. Gateway barley was the test crop, treated and sown at a rate of 91 kg/ha. N (as ammonium nitrate) and K (as potassium chloride) fertilizers were broadcast at time of seeding, whereas P (as treble superphosphate) fertilizer was drilled in with the seed. Each plot retained its treatment identity throughout the study. For example, plot number 6, site 01 annually received treatment number 5 (see Table 6). Sites were sprayed for weed control prior to heading.

Harvesting. Plots were harvested at maturity, usually requiring two or more harvest dates for a site due to treatment effect. Barley straw was returned to the plot, the amount determined by weight of straw harvested from the plot sample area.

Soil sampling. Soil sample cores were taken on a plot basis prior to seeding and after harvesting. Plot samples were divided into four sub-samples by depths:

Code	Depth, cm	Depth, in.
A	0.0 - 15.2	0 - 6
B	15.2 - 30.5	6 - 12
C	30.5 - 61.0	12 - 24
D	61.0 - 91.4	24 - 36

At sites in the Edmonton district plot samples were composites of four cores; in the Lacombe district a single core was taken as the plot sample. Two sets of plot samples were required prior to seeding, one set was used for moisture determination and the other set was prepared for soil testing. In the Edmonton district soil cores were split vertically to obtain sample pairs; in the Lacombe district a second soil core was taken as the duplicate plot sample. Plot samples taken after harvest were used only for soil moisture determination. Prior to soil sampling, "fill" soil was prepared to replace the soil core removed.

Dates of operations. Dates of certain field operations are set out in Table 7.

Meteorological observations. A meteorological station was established at each location with daily observations made by the co-operator at 0800 hours during the growing season. Observations included:

precipitation,

maximum and minimum air temperatures (in screen),

latent evaporation (Voltz[2] porous-disc atmometer) and

soil temperature at 10 cm, under sod.

During the 1967 growing season two additional instruments were installed at each site:

anemometer[3], 3-cup, dial type (at a height of 2 m) and

hygrothermograph[4], weekly chart (in screen).

The atmometer, described by Carder (1960), proved unreliable as the

[2] Product of Voltz Manufacturing Co., 126 Northwestern Ave., Ottawa 3.

[3] Product of Casella, London, England.

[4] Model No. 255, Science Associates Inc., Princeton, N.J., U.S.A.

TABLE 7. Dates of certain field operations

Site-year	Spring sampling	Seeding	Harvest	Fall sampling
0164	June 2	June 3	Sept. 4, 8	Sept. 17, 18
2164	May 28, 29	June 3	Sept. 4, 11	Oct. 5
0165	May 10, 11	May 12	Aug. 16	Aug. 25
0365	May 12, 13	May 14	Aug. 13, 14	Aug. 17, 20
0565	May 18, 20	May 21	Aug. 17	Aug. 23
2165	June 4	June 5	Sept. 7	Sept. 13
2365	May 19, 20	June 7	Sept. 8	Sept. 24
2565	May 21, 28	June 5	Sept. 8	Sept. 24, 28
0166	May 18	May 19	Aug. 22	Aug. 23
0366	May 25, 26	May 26	Aug. 26	Sept. 6
0566	May 16, 17	May 17	Aug. 11, 12	Aug. 18, 19
2166	May 3	May 10	Aug. 12, 19	Aug. 23
2366	May 4	May 11	Aug. 12, 18	Aug. 24
2566	May 5	May 11	Aug. 12, 19	Aug. 24
0167	May 24	May 29	Aug. 21, 25	Aug. 25
0367	May 23	May 24	Aug. 28	Aug. 31
0567	May 17, 18	May 18	Aug. 15, 21	Aug. 22
2167	May 10	May 17	Aug. 15, 18	Aug. 18
2367	May 19	May 20	Aug. 11, 18, 29	Aug. 29
2567	May 15	May 18	Aug. 14	Aug. 23
0168	May 21	May 22	Aug. 29, Sept. 9, 12	Aug. 30, Sept. 10, 12
0368	May 23, 24	May 24	Oct. 8, 9	Oct. 11
0568	May 29	May 30	Sept. 9, 27	Sept. 28
2168	May 14	May 18	Oct. 21	Oct. 30
2368	May 15	May 18	Aug. 30, Sept. 24	Sept. 27
2568	May 16	May 18	Aug. 30, Sept. 24	Sept. 27

following contributed to under- and over-estimates of evaporation:

(a) sensitivity of the instrument to wind gusts,

(b) improper re-assembly of the apparatus (usually a daily task) and

(c) plugging of disc pores.

A pair of seamless-steel access tubes for a neutron moisture meter were installed within the meteorological enclosure at each location.

Inspection of sites. For the first three years of the study a technician from the Department of Soil Science, University of Alberta, visited sites at intervals of two weeks. In 1967 weekly visits commenced and were made by a senior student selected from within the Faculty of Agriculture. While costly in time and transportation, the weekly visit improved several aspects of the field investigation. The designated tasks at the time of the site visit included:

(a) To record general observations on both barley and forage plots of weed growth, damage due to rodents, birds, hail, etc. and incidence of disease within the crops.

(b) To record observations on stages of barley development. A code system was used, similar to the modified Feekes scale for indicating the stage of development of wheat as described by Peterson (1965).

(c) To check and service meteorological instruments.

(d) To take readings with the neutron moisture meter.

Control over rodent damage, often a serious problem, was much improved by remedial action taken at the time of the weekly visits.

C. Laboratory procedures

Introduction

All sample preparation and much of the physical analyses of soils were shared between the laboratories at Edmonton and Lacombe. Chemical analyses of soil samples were done by the Alberta Soil and Feed Testing Laboratory (ASFTL) in Edmonton.

Sample preparation

Soil samples were received in the laboratory at Edmonton in tied polythene bags and at Lacombe in capped aluminum cylinders. Samples collected for moisture determination were dried to constant weight at a temperature of 105 C in a mechanical-convection oven. Samples collected for chemical analyses were dried at a temperature of 60 C, then milled to pass a 2 mm sieve opening.

Barley harvested from plots, contained in cotton sacks, was air-dried in a well-ventilated loft. After drying, each sample was weighed then threshed. The threshed grain was weighed and weight of straw estimated by difference. A representative portion of the grain was cleaned of chaff, weeds and broken kernels.

Chemical analysis of soils

Soil reaction (pH) was determined on a saturated paste after a retention time of 30 minutes, according to a procedure described by Doughty (1941), using a glass electrode pH meter.

<u>Electrical conductivity</u> (mmhos/cm) was determined on an extract from the saturation paste of the soil reaction determination. The extract was obtained after a retention time of 30 minutes and the conductivity of the filtrate measured using a Solu-bridge conductivity meter.

<u>Nitrate-nitrogen</u> (pounds N/acre six inches) content of soil samples was determined by a method adapted from the procedures of Harper (1924) and Prince (1945). A measured volume of soil (about 5 g) and 25 ml of extracting solution (0.02N copper sulphate and 0.007N silver nitrate) were shaken in a flask for 10 minutes. Calcium hydroxide (0.2 g) was added to the flask and shaking resumed for 10 minutes. Magnesium carbonate (0.5 g) was added to the flask and shaking resumed for 2 minutes. A 10 ml portion of a filtrate (Whatman No. 30 filter paper) was taken to dryness over low heat, then cooled. The residue was dissolved in 2 ml of phenoldisulphonic acid and allowed to stand for 10 minutes before dilution with water and 20 ml of 7.5N ammonium hydroxide solution to a volume of 50 ml. The colour intensity was read on a spectrophotometer at a wavelength of 415 μ, using a flow-through cuvette.

<u>Available phosphorus</u> (pounds P/acre six inches) was extracted by the Miller and Axley (0.03 M ammonium fluoride and 0.015 M sulphuric acid) method described by Robertson (1962). The P in the extractant was determined by measuring the vanadomolybdophosphoric yellow colour by spectrophotometry.

<u>Exchangeable potassium</u> (pounds K/acre six inches) was extracted

by 1.0N ammonium acetate. Soil (5 g) and extracting solution (25 ml) were shaken for 5 minutes. Potassium in the filtrate was determined by flame photometry.

Physical analysis of soils

Mechanical analysis of soil samples followed the pipette procedure described by Toogood and Peters (1953), except that carbonates were removed by the addition of hydrochloric acid.

Soil bulk density was determined by weight/volume measurements on samples obtained by a core-sampler. On two soils, a Chernozemic and a Luvisolic, this method was compared to the time-consuming method of collecting large cores (6 x 12 cm) from an exposed soil profile. Variation in bulk density was greater between sampling points in a field than between methods. Provided a correction is applied for any observed compaction, several samples collected by a core-sampler gave a reasonable estimate of average bulk density for the area sampled.

Field capacity moisture content per cent was estimated by a method using a pressure-plate apparatus at one-third atmosphere pressure, as described in U.S.D.A. Handbook 60 (1954). Moisture content was expressed on an oven dry-weight basis.

Permanent wilting point (lower limit of soil moisture available to the plant) moisture content per cent was estimated by a method using a pressure-membrane apparatus (cellulose casing membrane) at 15 atmospheres pressure as described in U.S.D.A. Handbook 60 (1954). Moisture content was expressed on an oven dry-weight basis.

RESULTS AND DISCUSSION

Before proceeding with the analysis of barley yield data, a brief description is presented of soil chemical and physical characteristics of the six sites. Site average soil test data of samples collected prior to the first application of fertilizers to plots are presented in Table 8. Results of mechanical analysis of these soils are listed in Table 9 and apparent densities, moisture-holding characteristics and moisture status at time of seeding are presented in Table 20. Certain features will be noted:

(a) Soil test values indicate marked differences between sites in soil nutrient status at the start of the study.

(b) Soils are medium-textured, classes include loams, clay loams and sandy loams. Site 21, a Ponoka Sandy Loam with low clay content in the upper 60 cm, has the lowest available moisture capacity.

(c) Total carbon (which is mostly organic carbon) is much higher in Chernozemic than in Luvisolic soils.

A. Barley response to applied nutrients

In this section the relationship between barley yield and applied fertilizers is considered from the point of view of expressing yield as a function of the various nutrients applied, that is

$$Y = f(N_A, P_A, K_A), \tag{4}$$

where Y represents barley yield and the variables N_A, P_A, K_A are the

TABLE 8. Soil test data: averages of initial site samples[a]

Site	Depth cm	pH	Cond. mmhos/cm	Total Carbon[b] %	Available soil nutrients kg/ha N	P	K
Chernozemic soils							
01	0-15	5.9	0.4	6.0	34	8	265
	15-30	5.8	0.5	3.5	43	2	304
05	0-15	6.5	0.5	4.5	13	24	338
	15-30	6.5	0.4	0.9	6	8	347
21	0-15	6.0	0.4	5.2	21	45	
	15-30	6.2	0.4	3.9	47	10	
Luvisolic soils							
03	0-15	5.5	0.3	1.3	4	7	295
	15-30	4.5	0.3	0.6	2	2	416
23	0-15	6.4	0.3	1.2	3	59	334
	15-30	6.0	0.3	0.4	2	18	382
25	0-15	6.5	0.5	1.6	17	112	760
	15-30	6.3	0.4	0.4	6	26	344

[a] Initial samples are samples collected prior to the first application of fertilizer treatments. Except for carbon, there are 48 observations in each average.

[b] Total carbon (mainly organic carbon) using Leco Induction Furnace. For this analysis only, composites of samples collected in 1968 were analyzed.

TABLE 9. Mechanical analysis of soils

Site	Depth cm	per cent Sand	Silt	Clay	Textural class
01	0-15	24	46	30	Clay Loam
	15-30	24	46	30	Clay Loam
	30-61	24	38	38	Clay Loam
	61-91	24	37	39	Clay Loam
03	0-15	38	44	18	Loam
	15-30	32	32	36	Clay Loam
	30-61	32	28	40	Clay, Clay Loam
	61-91	35	30	35	Clay Loam
05	0-15	38	36	26	Loam
	15-30	36	34	30	Clay Loam
	30-61	36	33	31	Clay Loam
	61-91	36	36	28	Loam, Clay Loam
21	0-15	57	25	18	Sandy Loam
	15-30	53	27	20	Sandy Loam, Sandy Clay Loam
	30-61	50	28	22	Loam
	61-91	12	48	40	Silty Clay, Silty Clay Loam
23	0-15	44	44	12	Loam, Sandy Loam
	15-30	44	30	26	Loam
	30-61	46	30	24	Loam
	61-91	46	30	24	Loam
25	0-15	44	47	9	Sandy Loam
	15-30	44	35	21	Loam
	30-61	38	34	28	Loam, Clay Loam
	61-91	38	34	28	Loam, Clay Loam

rates of applied nitrogen, phosphorus and potassium fertilizer, respectively. The following second order regression model was considered:

$$Y = a_0 + a_1N_A + a_2P_A + a_3K_A + a_{11}N_A{}^2 + a_{22}P_A{}^2 + a_{33}K_A{}^2 + a_{12}N_A \cdot P_A + a_{13}N_A \cdot K_A + a_{23}P_AK_A + \text{error term } (\varepsilon) \qquad (5)$$

where the a_{ij} (i,j = 1,2,3) are coefficients of the variables in the regression equation. The analysis of variance for each site-year on Chernozemic soils is set out in Table 10 and for each site-year on Luvisolic soils is set out in Table 11. The analyses indicate:

(a) The N and P treatments produced significant effects on barley yields, whereas the effect of K was not significant. This evidence supported the general fertilizer recommendation for cereal crops on soils of central Alberta.

(b) The lack of significant effects of applied nutrients at site 21. This result reflected the high soil nutrient status of the site.

(c) Deviations from quadratic regression were generally significant. The influence of soil nutrients on treatment effects probably contributed to this lack of fit.

In view of the analyses of variance, it was of interest to examine a reduced form of equation 5, eliminating K as a factor in the regression model:

$$Y = b_0 + b_1N_A + b_2P_A + b_{11}N_A{}^2 + b_{22}P_A{}^2 + b_{12}N_A \cdot P_A + \varepsilon \qquad (6)$$

Regression coefficients (b_{ij}) and the square of the correlation coefficient

TABLE 10. Analyses of variance of barley yields for 10 site-years on three Chernozemic soils[a]

Source of variation	df			Mean squares									
				0164	0165	0167	0565	0566	0567	2164	2165	2166	2167
Replicates	1			52.52**	22.26	27.55*	55.55*	4.45	1.53	16.74	86.15*	279.56**	0.21
Treatments	22												
Linear		3											
N			1	0.09	8.70	20.67*	154.03**	50.53**	167.75**	0.74	0.65	26.62	1.41
P			1	108.80**	10.53	52.73**	2.28	11.94	11.14	4.95	7.94	11.80	0.50
K			1	0.18	2.28	6.48	1.93	6.03	4.77	0.35	0.02	0.01	0.00
Quadratic		3		44.42**	69.59**	75.21**	140.26**	56.31**	85.68**	10.77	26.89	23.81	38.50**
Interactions		3											
NP			1	1.02	0.12	3.41	3.73	10.54	2.54	1.01	9.06	18.30	0.37
NK			1	2.34	0.25	0.99	0.99	0.47	0.56	0.90	0.91	3.57	0.06
PK			1	1.76	1.53	1.31	5.27	0.40	1.31	0.45	2.31	0.01	7.49
Deviations		13		23.42**	28.34**	29.54**	56.58**	26.09*	38.06**	9.91	25.99	32.42	14.57
Error	22			3.90	6.25	4.42	10.89	5.58	3.05	5.19	10.94	27.08	7.80
Total	45												

[a] Levels of significance are: **: 0.01
*: 0.05

TABLE 11. Analyses of variance of barley yields for 7 site-years on three Luvisolic soils[a]

Source of variation	df			Mean squares						
				0365	0367	2366	2367	2565	2566	2567
Replicates	1			1.08	5.81	68.42**	2.20	119.37*	2.85	69.03*
Treatments	22									
Linear		3								
N			1	72.28**	0.28	77.85**	27.36*	852.34**	196.08**	201.26**
P			1	79.03**	43.40**	2.18	26.41*	0.05	0.08	4.73
K			1	0.00	1.23	0.29	0.01	0.05	0.02	0.02
Quadratic		3		93.27**	32.58**	36.61**	61.17**	308.90**	89.03**	189.11**
Interactions		3								
NP			1	35.56**	2.12	1.76	10.80	2.87	6.88	6.91
NK			1	0.01	0.65	3.66	2.00	0.02	0.05	1.89
PK			1	0.97	0.16	5.84	0.81	1.16	0.08	0.34
Deviations		13		51.72**	15.99**	20.06	34.76**	160.61**	48.81**	75.25**
Error	22			3.92	2.88	7.47	3.72	24.85	6.30	12.23
Total	45									

[a] Levels of significance are: **: 0.01
*: 0.05

(R^2) of this equation for each of the 17 site-years are presented in Appendix C. Regression analysis, using equation (6), was also carried out for grouped site-years. The regression coefficients (b_{ij}) and R^2 values are presented in Table 12 for three regression equations which include in regression (a) all 17 site-years (b) 10 site-years on Chernozemic soils and (c) 7 site-years on Luvisolic soils. Comparing each b_{ij} in equation (a) with its counterparts in (b) and (c), only slight differences are found, indicating that the three equations describe similar response surfaces. However, for Luvisolic soils the response surface is poorly defined, as indicated by large standard errors of the regression coefficients for linear and quadratic P. Regression coefficients of site-year equations (Appendix C) vary both in sign and magnitude. Differences in site-year regression come from several sources which include:

(a) differences in soil nutrient status over the sites,

(b) residual differences (treatment effects) over the years and

(c) interrelationships of weather variables with mineral nutrients.

B. Effect of soil nutrient levels on barley response to applied nutrients

The experimental data were examined by considering a regression equation of the form:

TABLE 12. Three regression equations for yield of barley as a function of applied N and P, showing regression coefficients, standard errors of estimate of regression coefficients and R^2 values

Variable	All 17 site-years		10 site-years on Chernozemic soils		7 site-years on Luvisolic soils	
	b_i	s_b	b_i	s_b	b_i	s_b
Intercept	16.18130		17.84416		13.81168	
N_A	0.14340**	0.02028	0.12884**	0.02308	0.16363**	0.03509
P_A	0.18020**	0.05063	0.18194**	0.05772	0.17855	0.08775
N_A^2	-0.00077**	0.00014	-0.00077**	0.00016	-0.00077**	0.00025
P_A^2	-0.00295**	0.00090	-0.00263*	0.00102	-0.00342	0.00156
$N_A \cdot P_A$	0.00041*	0.00021	0.00021	0.00024	0.00069	0.00036
R^2	0.227		0.205		0.294	

Significance levels: ** 0.01
* 0.05

$$Y = c_0 + c_1N_A + c_2P_A + c_3N_S + c_4P_S + c_{11}N_A^2 + c_{22}P_A^2$$
$$+ c_{33}N_S^2 + c_{44}P_S^2 + c_{12}N_A \cdot P_A + c_{13}N_A \cdot N_S + c_{14}N_A \cdot P_S$$
$$+ c_{23}P_A \cdot N_S + c_{24}P_A \cdot P_S + c_{34}N_S \cdot P_S + \varepsilon \qquad (7)$$

where the additional variables N_S and P_S represent soil test values for nitrate-nitrogen and available phosphorus, respectively.

At this point a decision was needed regarding depth of sampling for soil nutrients. Usually the established soil testing procedures would apply, but the 6-inch (15.2 cm) sampling depth has been questioned by several workers, particularly in assessing N_S status of soils of the province. Faced with a possible change in depth of sampling, the problem was to anticipate the nature of the revised procedure.

Using equation (7) four depths of sampling for N_S (0-6", 0-12", 0-24" and 0-36") and two depths of sampling for P_S (0-6" and 0-12") were compared. Regression statistics were generated for (a) individual site-years and (b) various groupings of site-years: by sites, by years, etc. The regression coefficients were tested for parallelism by a method described by Williams (1959). The predictive value of various sampling depths were compared by examining the squared correlation coefficients. These comparisons indicated:

(a) The available phosphorus status of the soil could be adequately described by sampling to a depth of six inches.

(b) The nitrate-nitrogen status of the soil is inadequately described by sampling to a depth of six inches.

(c) The regressions were not significantly different for N_S at the 12-, 24- and 36-inch depths.

Anticipating an eventual change in sampling procedure for the province of Alberta, hereafter in this study the value of N_S shall represent nitrate-nitrogen of the soil to a depth of 24 inches (61 cm) and P_S shall represent available phosphorus to a depth of 6 inches (15.2 cm). While a 12-inch sampling depth appears adequate from the evidence examined, it is probable that the 24-inch sampling depth for N_S used in Manitoba and Saskatchewan is more appropriate for assessing the nitrate-nitrogen status of summerfallowed fields.

Regression coefficients (c_{ij}, i,j = 1,2,3,4) and squared correlation coefficient (R^2) of equation (7) for each of 17 site-years are tabulated in Appendix D. The regression coefficients (b_i) and R^2 values are presented in Table 13 for three regression equations which include in regression (a) all 17 site-years (b) 10 site-years in Chernozemic soils and (c) 7 site-years on Luvisolic soils.

Comparing the two regression equations having 17 site-years in the regression (Table 12, equation (a) with 5 variables and Table 13, equation (a) with 14 variables) certain features emerge:

(a) Adding soil variables to the regression increased R^2 from 0.227 to 0.386. (Elimination of some non-significant variables will be dealt with later.)

(b) Setting soil test values equal to zero, both equations now describe barley yield as a function of the same five variables (applied

TABLE 13. Three regression equations for yield of barley as a function of applied and soil N and applied and soil P, showing regression coefficients, standard errors of estimate of regression coefficients and R^2 values

Variable	All 17 site-years		10 site-years on Chernozemic soils		7 site-years on Luvisolic soils	
	b_i	s_b	b_i	s_b	b_i	s_b
Intercept	11.01667		10.62956		12.42906	
N_A	0.14415**	0.01916	0.13425**	0.02147	0.2008**	0.02970
P_A	0.18279**	0.04731	0.14106**	0.05345	0.12089	0.07327
N_S	0.06035**	0.01253	0.04754**	0.01337	-0.18174**	0.05132
P_S	0.05369**	0.01666	0.22297**	0.03133	0.04869*	0.02054
N_A^2	-0.00073**	0.00013	-0.00066**	0.00015	-0.00086**	0.00020
P_A^2	-0.00212**	0.00082	-0.00207*	0.00092	-0.00126	0.00123
N_S^2	-0.00011*	0.00005	-0.00018**	0.00006	0.00167**	0.00045
P_S^2	-0.00014	0.00008	-0.00129**	0.00020	-0.00033**	0.00010
$N_A \cdot P_A$	0.00019	0.00020	0.00013	0.00024	0.00045	0.00031
$N_A \cdot N_S$	-0.00041**	0.00008	-0.00017*	0.00008	-0.00152**	0.00039
$N_A \cdot P_S$	0.00038**	0.00010	-0.00011	0.00019	0.00043**	0.00013
$P_A \cdot N_S$	-0.00018	0.00019	0.00013	0.00021	-0.00125	0.00084
$P_A \cdot P_S$	-0.00083**	0.00025	-0.00055	0.00049	-0.00063	0.00033
$N_S \cdot P_S$	0.00034**	0.00012	0.00024	0.00016	0.00220**	0.00037
R^2	0.386		0.399		0.594	

Significance levels: ** 0.01
* 0.05

nutrients only). The surfaces described are very similar but on different planes with respect to the Y-axis.

(c) Surface similarities decrease as N_S or P_S increase. Regression coefficients of $N_A.N_S$ and $P_A.P_S$ are negative and highly significant, augmenting negative curvature exerted by $N_A{}^2$ and $P_A{}^2$.

The nitrogen and phosphorus treatments influenced the soil nutrient status in subsequent years. A summary over years of the residual effect of treatments on N_S and P_S is presented in Table 14. In addition to the effect of treatments on magnitude and range of N_S and P_S values the following points can be noted from the table:

(a) A sufficiency of one nutrient suppresses the "build-up" of the other nutrient in the soil because plant growth is not restricted.

(b) A deficiency of one nutrient can result in the "build-up" of the other nutrient at higher treatment levels.

(c) The N_S status of all plots at site 03 increased sharply after the first season of cropping. This site had been in pasture for many years and apparently the potential was high for mineralization of organic forms of nitrogen.

It is seen that less than 40 per cent of the variability in barley yield between 816 plots in the study can be explained as effects of fertilizer treatments or soil nutrient status. It is evident that equation (7) does not consider other variables known to influence yield, such as certain physical properties of the soil environment and components of weather influencing the atmospheric environment. The variation due to these other factors is lumped into the error (residual) variation in the regression analysis.

TABLE 14. Residual nutrient status of plots under continuous barley production to show the effect of fertilizer treatment[a]

		Soil test values (kg/ha) averaged over plots									
		Nitrate-nitrogen (N_S) to depth of 61 cm					Available phosphorus (P_S) to depth of 15 cm				
		Nitrogen treatment, kg/ha					Phosphorus treatment, kg/ha				
Site-year		0	34	67	101	134	0	13	27	40	54
Chernozemic soils											
01	1964	102	118	108	108	111	8	9	9	8	7
	1965	57	90	96	144	157	20	21	27	27	34
	1966	34	36	47	60	86	10	16	19	24	29
	1967	20	18	34	52	94	9	13	20	25	32
	1968	16	17	21	27	78	10	13	15	34	38
05	1965	27	27	22	24	26	24	22	22	26	25
	1966	20	19	24	24	28	16	18	20	25	36
	1967	31	36	36	44	58	20	25	28	47	49
	1968	7	10	15	13	46	13	22	20	24	34
21	1964	195	156	183	177	197	46	46	43	45	52
	1965	109	144	127	153	168	49	53	53	67	66
	1966	74	81	100	116	159	41	53	82	78	99
	1967	50	69	63	73	153	52	57	93	97	125
	1968	46	59	108	150	227	31	49	83	96	139
Luvisolic soils											
03	1965	10	9	12	10	15	6	9	6	7	7
	1966	43	44	41	45	55	17	17	20	27	30
	1967	43	46	58	67	101	12	13	19	38	29
	1968	31	45	63	81	119	9	11	20	25	31
23	1965	9	10	9	10	10	62	59	63	58	58
	1966	29	32	31	34	40	53	54	81	63	68
	1967	31	31	34	34	45	62	75	103	96	110
	1968	22	30	44	73	113	47	71	97	119	172
25	1965	24	29	28	37	24	111	114	120	116	100
	1966	17	18	22	31	34	96	103	106	106	109
	1967	31	37	31	49	53	102	109	141	143	164
	1968	34	40	63	105	146	91	123	156	172	186

[a] Number of plots in averaged values are: 12, 8, 10, 8 and 10, in order of increasing treatment level. Interaction effects, if present, are confounded by this one-way summary.

At this time prior knowledge directs attention to the role of soil moisture conditions in the growth and development of cereal crops. The need arises for some measure or index of the soil moisture regime, such that a soil moisture variable of some predictive value can be introduced into the yield equation.

C. Effects of moisture stress on yield of barley

The analysis presented here is based on data obtained in a prior study (1959 - 1963) that measured the response of Gateway barley to applied fertilizers. Field techniques and site locations of this prior study were described earlier in the text. Aspects of the methodology used in the analysis of the relationships between soil moisture-stress and yield of barley are outlined briefly:

(a) Moisture-holding properties were determined on soil samples collected from the 27 experimental sites.

(b) A site daily soil moisture budget was computed using a technique described by Baier and Robertson (1966) for which potential evaporation was estimated by a modified Penman equation.

(c) Stages of barley development were divided into seven intervals: (1) planting - emergence (2) onset of tillering (3) jointing (4) heading (5) milk (6) soft-dough and (7) hard-dough stage.

(d) The drought-day criterion described by Van Bavel (1953) was used to identify moisture-stress days. Severity of drought within an interval was described as: drought-days/total-days in interval.

(e) The effect of moisture-stress on yield was studied by using a

linear model with yield regressed on seven (interval) drought ratios. Site yield was described by using at least 10 per cent of the 150 plots, those for which nutrients were not limiting.

Soil moisture budget

The soil moisture budget equation advanced by Baier and Robertson (1966) and a modification described by Baier (1969) were studied. The budgeting technique makes use of the concept of potential evaporation (PE) as an indicator of the possible maximum loss of water from the soil. It is convenient to present the equation used in the original model for estimating daily actual evapotranspiration (AE):

$$AE_i = \sum_{j=1}^{n} k_j \frac{S'_{j(i-1)}}{S_j} Z_j \, PE_i \, e^{-\omega(PE_i - \overline{PE})} \qquad (8)$$

where

AE	=	actual evapotranspiration for day i ending at the morning observation of day i + 1.
$\sum_{j=1}^{n}$	=	summation carried out from zone j = 1 to zone j = n.
k_j	=	coefficient accounting for soil and plant characteristics in the jth zone.
$S'_{j(i-1)}$	=	available moisture in the jth zone at the end of day i - 1, that is, at the morning observation of day i.
S_j	=	capacity for available water in the jth zone.
Z_j	=	adjustment factor for different types of soil dryness curves.
PE_i	=	potential evapotranspiration for day i.

ω = adjustment factor accounting for effects of varying PE rates on AE/PE ratio.

$\overline{PE}$ = average PE for month or season.

A feature of the model is that the total available water in the soil is divided into several zones of varying capacities. Simulation of actual moisture loss from the soil, by evaporation and by transpiration, is obtained by progressive withdrawal of moisture from different depths in relation to the rate of PE and the available moisture in each zone and root development. The growing period is divided into intervals (growth stages). Within each interval k-coefficients are assigned in accord with an assumed water extraction pattern of the crop (Table 21).

For this study a rooting depth for barley was assumed, defined by that depth of soil with a capacity of 4.00 inches (10 cm) available soil moisture. By this assumption rooting depth varied from 62 cm at site 03 (a Cooking Lake Loam) to 89 cm at site 21 (a Ponoka Sandy Loam). From curves depicted by Baier and Robertson (1966, p. 304) a type "E" drying-curve was chosen to describe the potential gradient developed during drying of the medium-textured soils used in this investigation.

The budgeting equation requires input of daily PE and a slightly modified Penman equation was used to estimate this site variable. Several problems were encountered in using the Penman equation, such as printing errors in the Smithsonian Meteorological Tables, List (1949) of two ancillary equations, one of which has been corrected by List (1968). While detailed notes are presented in Appendix F on the variables entering the Penman equation, certain variables to be discussed in this section are defined:

r is the albedo or reflection coefficient, that portion of incident solar radiation that is reflected from the surface.

e_a is the saturation vapour pressure (mm Hg) of the atmosphere.

e_d is the actual (observed) vapour pressure of the atmosphere.

$e_a - e_d$ is the vapour pressure deficit of the atmosphere.

u is the wind (miles per day) observed at a height of 200 cm.

Budget input data for experimental sites 1959 - 1963

It was decided to estimate the relationship between moisture stress and yield of barley from observations external to the 1964 - 1968 study. Data obtained from field experiments 1959 - 1963 were selected for this purpose. This source was selected because:

(a) Field moisture conditions had been determined prior to seeding.

(b) Samples could be collected from the sites for determination of moisture-holding characteristics for these soils.

(c) Field notes were sufficient to define stages of crop growth.

(d) Variation in yield of barley due to nutrient effects could be eliminated by using only data from high-yielding treatments.

(e) Site daily PE could be estimated from meteorological observations at Edmonton Industrial Airport.

(f) Site rainfall had been recorded, though only at the irregular intervals of site visits.

Site soil moisture contents at 1/3 and 15 atm pressure were determined and the difference in moisture contents at the two pressures is taken as the available moisture capacity. Site data are set out in Appendix E, showing moisture characteristics, soil densities and available moisture contents.

Input data (excluding daily rainfall and PE) for the soil moisture budget equation for the 27 experimental sites are recorded in Table 15. The problem that rainfall observations of sites were periodic rather than daily was not too serious, because days of rainfall are usually regional in pattern. Site rainfall data were distributed over days after rainfall records of adjacent stations reporting daily rainfall had been examined. A summary of site rainfall is presented in Table 16.

Daily potential evaporation (PE) for the soil moisture budget equation was calculated by the Penman equation, using meteorological observations at Edmonton Industrial Airport. Differences in site albedos (see Appendix F) were considered in calculating PE: estimated initial albedos are listed in Table 15 and an albedo of 0.18 was assumed appropriate for a complete barley cover. From the meagre data available, estimates of PE for central Alberta as determined by four methods are compared in Table 17. The need for consistency of method in estimating PE is indicated by the marked differences between the results obtained by the four methods.

Budget input data for experimental sites 1964 - 1968

The planned collection of site data was sufficient to meet the needs of the budget equation. Failure of the porous-disc atmometer to supply a reliable estimate of site PE posed a difficult problem, because in some cases elements of the site environment influenced unmeasured meteorological variables used in computing a Penman estimate

TABLE 15. Site data entered in the equation for estimating a daily soil moisture budget for 27 site-years 1959 - 1963

Site-year	Soil albedo	Date seeded	Days from seeding to onset of development stage[a] E	J	H	Mi	SD	HD	Total available moisture of zone 0.20"	0.30"	0.50"	1.00"	1.00"	1.00"
									Available moisture of zone at seeding					
0259	0.12	May 27	13	35	45	58	71	84	0.16	0.24	0.40	0.54	0.21	0.21
0359	0.12	May 26	14	36	46	59	72	85	0.13	0.19	0.32	0.63	0.63	0.63
0160	0.18	May 31	11	34	44	56	68	80	0.20	0.30	0.50	1.00	1.00	1.00
0260	0.12	May 30	10	31	42	55	68	80	0.20	0.30	0.50	1.00	1.00	1.00
0360	0.12	May 30	12	35	46	59	72	84	0.20	0.30	0.50	1.00	1.00	1.00
0460	0.12	May 25	14	38	49	62	75	87	0.11	0.17	0.28	0.40	0.10	0.10
0560	0.15	May 25	14	38	49	62	75	87	0.17	0.25	0.42	0.22	0.22	0.22
0361	0.12	May 25	11	35	47	60	73	86	0.18	0.27	0.45	0.50	0.50	0.50
0561	0.18	May 18	12	38	50	63	76	89	0.10	0.15	0.20	0.30	0.30	0.30
0661	0.18	May 19	11	37	49	62	75	88	0.09	0.14	0.23	0.46	0.30	0.25
0761	0.18	May 23	11	34	45	58	71	83	0.15	0.22	0.37	0.50	0.35	0.35
0861	0.21	May 26	10	32	43	56	69	81	0.18	0.27	0.45	0.90	0.65	0.65
0961	0.18	May 23	11	34	45	58	71	83	0.20	0.30	0.50	1.00	0.55	0.40
1061	0.15	May 24	12	34	45	58	71	83	0.14	0.21	0.35	0.70	0.65	0.55
0562	0.15	June 19	10	32	42	55	68	81	0.20	0.30	0.50	0.70	0.70	0.70
0762	0.18	June 8	9	31	41	53	65	77	0.20	0.30	0.50	1.00	1.00	1.00
0862	0.21	May 31	11	34	45	57	69	81	0.18	0.27	0.45	0.80	0.50	0.50
0962	0.18	June 8	9	31	42	55	68	81	0.20	0.30	0.50	1.00	1.00	1.00
1062	0.15	June 7	9	31	42	55	68	81	0.20	0.30	0.50	1.00	1.00	0.40
1162	0.18	May 24	11	32	42	55	68	81	0.18	0.27	0.45	0.67	0.67	0.67
1262	0.18	May 31	11	33	44	57	70	83	0.20	0.30	0.50	1.00	0.90	0.40
0563	0.18	May 27	10	31	42	55	68	81	0.13	0.20	0.33	0.50	0.15	0.15
0763	0.21	May 30	11	32	43	56	69	82	0.10	0.15	0.25	0.30	0.20	0.20
0863	0.21	May 28	12	34	45	58	71	84	0.12	0.18	0.30	0.50	0.40	0.10
0963	0.18	May 30	11	32	43	56	69	82	0.12	0.18	0.30	0.55	0.40	0.40
1063	0.15	May 29	12	33	44	57	70	83	0.08	0.12	0.20	0.40	0.35	0.25
1163	0.18	May 27	10	31	42	55	68	81	0.17	0.26	0.43	0.90	0.80	0.32

[a] Development stages: emergence, jointing, heading, milk, soft dough, hard dough.

TABLE 16. A summary of rainfall[a] for 27 site-years 1959 - 1963

Site-year	Date seeded	Inches rainfall for eight intervals after date seeded: 10-day interval number 1	2	3	4	5	6	7	8
0259	May 27	0.06	1.34	1.52	0.19	0.49	0.47	1.72	1.61
0359	May 26	0.06	1.34	1.00	0.19	0.49	0.47	1.46	1.14
0160	May 31	0.34	0.50	1.41	0.15	0.43	0.52	3.82	0.43
0260	May 30	0.34	0.30	1.91	0.17	0.43	0.52	4.18	0.35
0360	May 30	0.34	0.30	1.91	0.17	0.43	0.52	4.18	0.35
0460	May 25	0.01	0.33	1.01	1.55	0.37	0.43	1.02	0.82
0560	May 25	0.01	0.33	1.01	1.00	0.37	0.43	1.02	1.32
0361	May 25	0.30	0.10	0.50	0.50	0.25	2.15	0.25	0.05
0561	May 18	0.30	0.00	0.45	0.60	0.75	0.90	5.40	0.55
0661	May 19	0.30	0.00	0.45	0.60	1.25	1.00	1.75	0.50
0761	May 23	0.42	0.20	1.48	1.40	0.00	0.50	0.50	0.20
0861	May 26	0.42	0.78	1.20	0.50	0.50	1.60	0.58	0.20
0961	May 23	0.42	0.20	1.18	1.30	0.00	1.05	1.75	0.20
1061	May 24	0.42	0.68	0.72	1.58	0.00	1.65	1.35	0.18
0562	June 19	0.26	1.12	0.86	0.87	1.83	0.00	0.55	0.55
0762	June 8	1.80	0.15	0.65	1.17	0.50	2.43	0.29	0.11
0862	May 31	0.60	1.20	0.80	1.24	1.46	0.20	1.50	0.00
0962	June 8	1.80	0.15	0.35	1.17	0.49	1.44	0.29	0.19
1062	June 7	1.30	0.15	0.40	1.22	0.38	2.55	0.00	0.64
1162	May 24	1.41	2.48	0.65	0.99	0.67	0.85	0.32	1.73
1262	May 31	1.94	2.39	0.70	0.30	0.97	0.61	1.38	0.00
0563	May 27	0.60	1.50	0.40	1.20	0.80	0.40	0.05	0.45
0763	May 30	0.05	0.25	0.05	0.95	1.20	0.21	0.05	0.24
0863	May 28	0.05	0.45	0.10	0.25	0.75	0.40	0.10	0.40
0963	May 30	0.05	0.25	0.05	0.60	0.55	0.41	0.05	0.24
1063	May 29	0.00	0.20	0.05	0.75	1.20	0.26	0.10	0.54
1163	May 27	0.40	1.05	0.35	1.20	0.80	0.40	0.05	0.25

[a] Summarized from an estimated distribution of rainfall (see text) recorded.

TABLE 17. Comparison of some estimates of potential evaporation

	Monthly total evaporation, inches water				
	May	June	July	August	September
Penman estimate, data Edmonton Industrial Airport					
1959	4.78	4.74	5.94	3.57	2.45
1960	4.74	5.00	5.93	3.95	2.80
1961	5.02	6.18	5.34	4.58	2.49
1962	4.15	5.27	4.75	4.01	2.62
1963	4.64	6.26	6.72	5.25	3.48
1964	5.15	6.09	6.52	4.81	2.65
1965	5.26	5.41	6.05	4.75	2.31
1966	6.00	5.60	5.68	4.03	3.18
1967	4.75	5.31	5.36	4.95	3.99
1968	5.34	5.02	5.27	3.63	2.18
Average	4.98	5.49	5.76	4.36	2.82
Sunken-tank evaporimeter[a], Lacombe Research Station, Can. Dept. Agr.					
1959		3.93	5.09	2.86	
1960		4.54	5.09	3.86	
Long-term average	3.25	3.48	4.17	3.44	2.06
Estimate[b], data Edmonton Industrial Airport					
Long-term average	3.5	3.9	4.6	3.5	1.8
Class "A" open-pan evaporimeter, Edmonton International Airport					
1967				6.91	6.82
1968	8.80	7.47	7.62	4.81	3.31
1969	7.16	8.77	8.17	7.65	3.89

[a] Robertson, Geo. W. 1964. Evaporation measurements. Publ. 1210, Agrometeorological Section, Plant Research Institute, Research Branch, Can. Dept. Agr.

[b] Coligado, M. C., W. Baier and W. K. Sly. 1968. Risk analyses of weekly climatic data for agricultural and irrigation planning. Tech. Bull. 45, Agrometeorological Section, Plant Research Institute, Research Branch, Can. Dept. Agr.

of PE. Degree of exposure, with its consequent effects on humidity and wind speed, was the one site characteristic of special concern:

- site 05 was highly exposed. Situated on a prominent ridge, the winds were relatively high.
- site 23 was protected from prevailing winds, within the shelter of a crescent of trees.
- sites 01 and 25 were partially protected from prevailing winds by surrounding vegetation.

To measure site wind and humidity relationships, an anemometer and a thermohygrograph were set out at each site late in the 1967 season.

In order to estimate the missing wind and humidity observations for some of the 17 site-years the following linear regressions for known observations were used:

$$Y = b_0 + b_1 X$$

where values of Y are site observations of humidity (or wind) and values of X are corresponding observations at a reference station. The coefficients of these regressions are given in Table 18. Edmonton Industrial Airport (E Ind A) and Lacombe Research Station (Lac CDA) were used as reference stations. There were some differences in the nature of the observations:

- wind observations were at different heights above ground level: sites at 2.0 m, E Ind A at 17.4 m and Lac CDA at 12.2 m. Reference station wind observations were reduced to equivalent winds at a height of 2.0 m using the empirical power law (see Appendix F).

TABLE 18. Regression[a] of site observations (Y) on reference station observations (X) for daily wind and humidity

Reference station	Site	b_0	b_1	$\overline{X}$	$\overline{Y}$	n[b]	R	SEE
Wind (u) relationships[c]								
E Ind A	01	-3	0.868	149	127	232	0.82	31
E Ind A	03	14	0.847	148	140	229	0.82	30
E Ind A	05	13	1.080	148	173	230	0.82	39
Lac CDA	21	9	1.100	101	121	189	0.89	22
Lac CDA	23	27	0.657	102	94	224	0.58	38
Lac CDA	25	14	1.080	101	122	222	0.86	26
Vapour pressure of air (e_d)[d] relationships								
E Ind A	01	2.3	0.958	6.7	8.7	232	0.83	1.3
E Ind A	03	4.0	0.764	6.8	9.2	229	0.66	1.7
E Ind A	05	3.0	0.883	6.7	8.9	230	0.77	1.4
Lac CDA	21	2.2	0.872	7.3	8.5	189	0.81	1.2
Lac CDA	23	2.2	0.965	7.2	9.2	224	0.79	1.4
Lac CDA	25	2.4	0.801	7.3	8.3	222	0.74	1.3
Vapour pressure deficit (e_a - e_d) relationships								
E Ind A	01	-0.63	0.604	6.7	3.4	232	0.89	0.9
E Ind A	03	-0.64	0.512	6.6	2.8	229	0.76	1.4
E Ind A	05	-0.61	0.603	6.7	3.4	230	0.84	1.2
Lac CDA	21	-0.47	0.629	6.0	3.3	189	0.89	1.0
Lac CDA	23	-0.34	0.626	5.9	3.3	224	0.82	1.3
Lac CDA	25	0.05	0.604	5.9	3.6	222	0.81	1.4

[a] Equations used to estimate missing site values.

[b] Where (n) is number of observations.

[c] Reference station wind (mpd) reduced to equivalent wind at height of 2 m before linear relationships estimated.

[d] Units are mm Hg pressure for all humidity observations.

- site humidity calculations were based on abstracts from charts for 0500, 1100, 1700 and 2300 hours. Four e_a and four e_d values were calculated then averaged. Observations of wet- and dry-bulb temperatures at reference stations at 0800 and 1700 hours were used to calculate e_a and e_d values.

Input data (excluding[5] daily rainfall and PE) for the soil moisture budget equation are presented in Table 19. Moisture characteristics, soil densities and available water contents of the soils are recorded in Table 20.

Moisture stress equation

In a previous section yield equations were presented describing the relationship between yield of barley and levels of nitrogen (N_A, N_S) and phosphorus (P_A, P_S) available to the crop. Here a procedure will be described for obtaining a site index (W) of moisture stress. The index will later be incorporated into a yield equation of the form:

$$Y = f(N_A, N_S, P_A, P_S, W) \qquad (9)$$

The general procedure, showing relationships between the soil moisture budget equation, the Penman equation and a moisture stress equation,

[5] Available from the Department of Soil Science, University of Alberta.

TABLE 19. Site data entered in the equation for estimating a daily soil moisture budget for 17 site-years 1964 - 1967

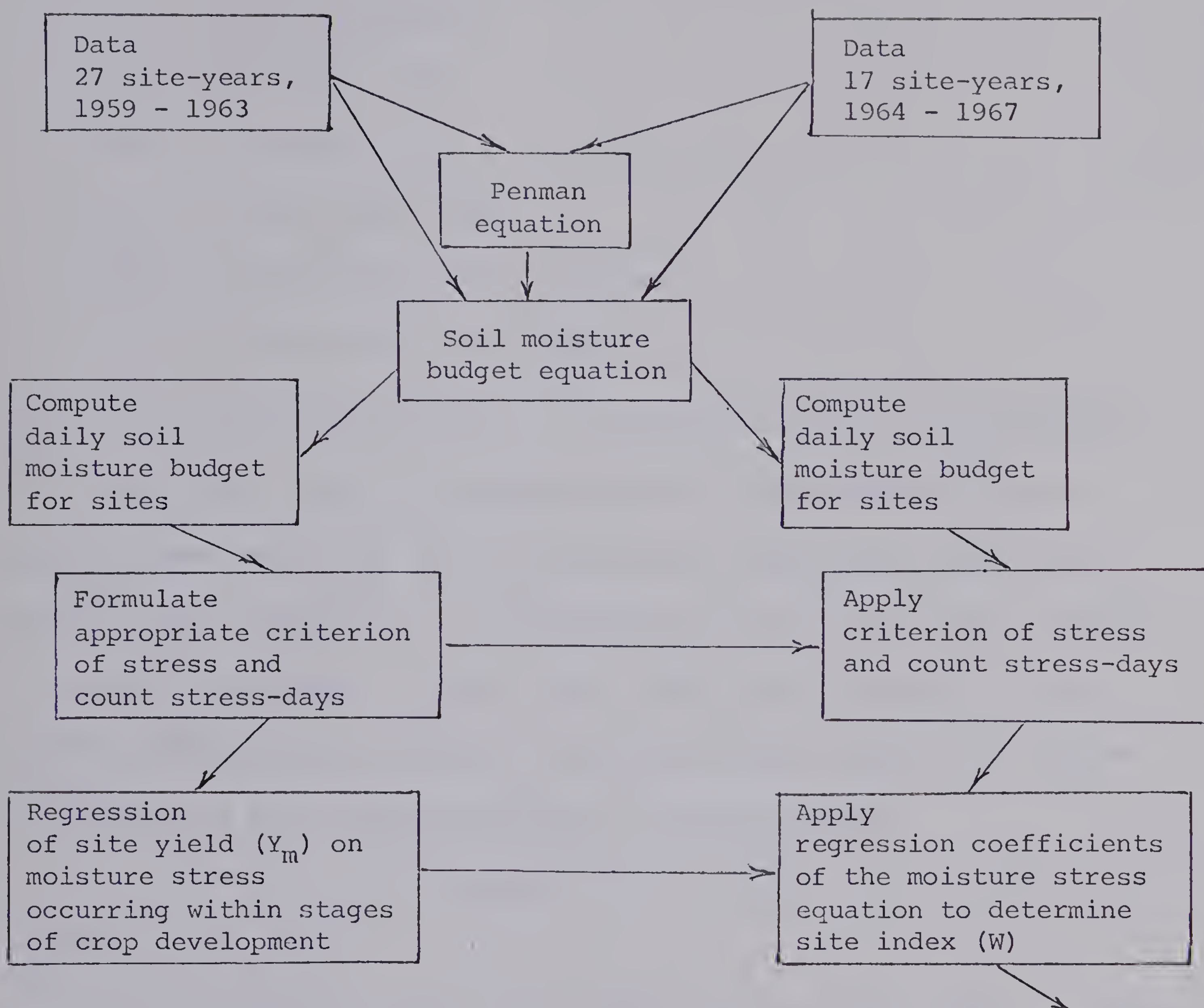
Site-year	Soil albedo	Date sampled	Date seeded	Days from seeding to onset of development stage[a]						Total available moisture of zone					
				E	J	H	Mi	SD	HD	0.20"	0.30"	0.50"	1.00"	1.00"	1.00"
										Available moisture of zone at seeding					
0164		June 2	June 3	10	32	43	58	74	91	0.09	0.14	0.23	0.43	0.18	0.18
0165	0.12	May 11	May 12	14	39	50	64	78	92	0.15	0.22	0.38	0.69	0.20	0.20
0167		May 24	May 29	10	31	43	58	66	74	0.14	0.22	0.36	0.57	0.24	0.24
0365	0.21	May 13	May 14	12	35	46	60	74	88	0.08	0.12	0.20	0.46	0.29	0.22
0367		May 23	May 24	15	36	48	67	76	86	0.06	0.08	0.14	0.52	0.19	0.50
0565	0.12	May 19	May 21	10	33	44	58	72	87	0.15	0.23	0.38	0.45	0.08	0.07
0566		May 17	May 17	10	35	46	59	73	87	0.14	0.21	0.35	0.57	0.25	0.24
0567		May 18	May 18	15	35	49	67	77	84	0.15	0.22	0.37	0.66	0.55	0.55
2164	0.12	May 29	June 3	10	33	44	60	77	96	0.15	0.22	0.44	1.00	0.24	0.15
2165		June 4	June 5	12	38	49	63	78	94	0.20	0.30	0.50	1.00	0.14	0.05
2166		May 3	May 10	14	42	53	67	82	97	0.20	0.30	0.50	1.00	0.10	0.00
2167		May 10	May 17	14	35	49	67	74	84	0.20	0.30	0.50	1.00	0.10	0.00
2366	0.21	May 4	May 11	14	42	53	67	81	96	0.16	0.24	0.40	0.43	0.19	0.22
2367		May 19	May 20	11	35	46	66	73	84	0.17	0.25	0.42	0.47	0.45	0.35
2565	0.21	May 25	June 5	11	38	49	63	78	94	0.20	0.30	0.50	0.96	0.69	0.69
2566		May 5	May 11	13	40	51	66	81	96	0.16	0.24	0.40	0.77	0.38	0.38
2567		May 15	May 18	13	34	48	66	73	83	0.20	0.30	0.50	0.96	0.68	0.68

[a] Development stages: emergence, jointing, heading, milk, soft-dough and hard-dough.

TABLE 20. Apparent densities and moisture characteristics of soils for experimental sites 1964 - 1968

			Moisture, per cent							Available water, inches					
					At time of seeding						At time of seeding				
Site	Depth, inches	d g/cm^3	1/3 atm	15 atm	1964	1965	1966	1967	1968	1/3 atm	1964	1965	1966	1967	1968
01	0- 6	1.00	35.5	19.5	26.6	31.5	31.9	31.0	25.9	0.96	0.43	0.72	0.74	0.69	0.40
	6-12	1.10	31.2	17.5	23.8	27.8	24.4	26.0	21.4	0.90	0.42	0.68	0.46	0.56	0.26
	12-24	1.59	27.6	14.0	16.4	16.7	18.1	17.2	15.5	2.59	0.46	0.52	0.78	0.61	0.23
	24-36	1.64	27.6	13.5	17.9	16.2	19.7	18.1	17.7	2.77	0.87	0.53	1.22	0.91	0.83
03	0- 6	1.38	20.3	8.0		13.0	12.5	11.5	9.8	1.02		0.41		0.29	0.15
	6-12	1.63	23.4	10.4		16.3	17.2	17.3	15.1	1.27		0.58		0.67	0.47
	12-24	1.64	24.3	10.9		13.9	18.8	17.6	16.1	2.64		0.59		1.32	1.02
	24-36	1.76	23.3	9.1		12.6	17.1	16.6	16.1	3.00		0.74		1.58	1.48
05	0- 6	1.11	28.7	13.1		25.0	23.9	24.6	18.4	1.04		0.79	0.72	0.77	0.35
	6-12	1.37	22.5	10.4		16.0	17.3	18.6	14.2	0.99		0.44	0.57	0.67	0.31
	12-24	1.55	22.1	10.2		11.0	13.0	16.7	11.3	2.21		0.15	0.52	1.21	0.20
	24-36	1.64	21.7	9.4		11.3	13.1	13.4	11.7	2.42		0.37	0.73	0.79	0.45
21	0- 6	1.18	27.8	17.0	25.1	37.1	29.7	30.6	19.4	0.76	0.57	0.76	0.76	0.76	0.17
	6-12	1.18	23.8	17.6	25.8	33.4	28.1	27.9	11.5	0.44	0.44	0.44	0.44	0.44	0.00
	12-24	1.36	15.7	10.2	16.0	22.7	17.0	17.1	13.4	0.90	0.90	0.90	0.90	0.90	0.52
	24-36	1.47	30.7	18.1	19.9	18.8	17.5	17.3	22.6	2.20	0.32	0.12	0.00	0.00	0.79
23	0- 6	1.48	18.6	7.4		21.8	16.4	17.0	10.8	0.99		0.99	0.80	0.85	0.30
	6-12	1.68	21.0	11.7		17.7	15.9	16.1	14.8	0.94		0.60	0.42	0.44	0.31
	12-24	1.71	22.8	13.0		16.9	14.9	17.4	13.4	2.01		0.80	0.39	0.90	0.08
	24-36	1.66	22.2	12.5		13.2	14.6	15.8	14.2	1.93		0.14	0.42	0.66	0.34
25	0- 6	1.43	18.0	5.8		23.3	15.5	21.9	10.2	1.05		1.05	0.83	1.05	0.38
	6-12	1.66	14.6	6.3		17.0	13.2	15.2	11.3	0.83		0.83	0.69	0.83	0.50
	12-24	1.76	20.1	8.5		16.5	12.9	16.4	11.6	2.45		1.69	0.93	1.67	0.65
	24-36	1.81	20.0	10.2		13.3	12.4	14.9	12.8	2.13		0.67	0.48	1.02	0.56

is illustrated in the following diagram:



The original soil moisture budget equation formulated by Baier and Robertson was used since the results were not altered appreciably by the modification to the equation suggested by Baier (1969). The growing period had been divided into six stages of development (see budgeting data, Tables 15 and 19) but, it became evident that for moisture stress analysis the second stage should be divided by identifying tillering. This increased the number of intervals from six

to seven:

(1) planting (P) to emergence(E),

(2) E to tillering (T),

(3) T to jointing (J),

(4) J to heading (H),

(5) H to milk stage (Mi),

(6) Mi to soft dough stage (SD) and

(7) SD to hard dough stage (HD).

Onset of tillering was assumed to be coincident with the appearance of the fourth leaf. Since the number of days in the interval E-J was usually about twice that of other intervals, sub-division gave approximately equal intervals. The development of tillers is highly dependent on external conditions. Jewiss (1966) noted that "prolonged environmental inhibition of an axillary bud progressively reduces its chances of producing a tiller when favourable conditions return".

A moisture stress equation for the 1959 - 1963 data was examined of the form:

$$Y = a_0 + a_1M_1 + a_2M_2 + a_3M_3 + a_4M_4 + a_5M_5 + a_6M_6 + a_7M_7 \qquad (10)$$

where Y represents barley yield, the M_i ($i = 1, 2, 3, \ldots, 7$) are indices of moisture stress occurring in the ith interval and the a_i are the regression coefficients.

The first step in formulating a criterion of moisture stress was to rearrange the computed soil moisture budget. For the purpose of stress analysis it seemed unnecessary that zones 1, 2 and 3 (total depth about 18 cm) should retain their separate identities. Hereafter these

three zones are referred to as "the first depth" (moisture budgets and k-coefficients summed). The criterion of stress now related to four depths, each with a capacity of 1.00 in. (2.5 cm) available soil moisture.

The k-coefficients described in an earlier section were retained as weighting factors in the stress analysis. The distribution of the coefficients over four depths for seven intervals is shown in Table 21 (procedure 1). Two features of this distribution are noted:

(a) A very abrupt change in magnitude of the k-coefficients occurs at the heading stage.

(b) Rooting depth is confined to about 18 cm until jointing stage. Field observations do not support this restriction.

A minor adjustment of the distribution of k-coefficients is presented in Table 21 (procedure 2). This adjustment allows lower depths to influence the count of stress-days more gradually and at an earlier stage of plant development. An available moisture index (AMI) was calculated daily for each site-year using both procedures 1 and 2. A sample calculation is presented:

The calculation is for the ith day, which occurs say, in the fourth interval (J-H). From the daily soil moisture budget assume the moisture contents of the four depths are 0.40, 0.70, 0.90 and 0.90 in., respectively. The k-coefficients are obtained from Table 21. The calculation of AMI by the two procedures:

<u>Procedure 1</u>:

$$\text{AMI} = (0.40'' \times 0.90) + (0.70'' \times 0.10) = \underline{0.430''}$$

TABLE 21. Comparison of k-coefficients used in two procedures for computing an available moisture index for stress analysis

Depth	Development stages of barley						
	P-E	E-T	T-J	J-H	H-Mi	Mi-SD	SD-HD
Procedure 1							
1	1.00	1.00	1.00	0.90	0.55	0.65	0.70
2				0.10	0.10	0.10	0.10
3					0.20	0.10	0.10
4					0.15	0.15	0.10
Procedure 2							
1	1.00	1.00	0.90	0.80	0.55	0.65	0.70
2			0.10	0.20	0.10	0.10	0.10
3					0.20	0.10	0.10
4					0.15	0.15	0.10

Procedure 2:

$$AMI = (0.40'' \times 0.80) + (0.70'' \times 0.20) = \underline{0.460''}$$

A value of the AMI < 0.450 was chosen as the criterion of a drought (moisture stress) condition. This selection was made after comparing the fit (using R^2 as a measure) obtained in the moisture stress equation (10) of several criteria of drought.

The ratio stress-days/total-days was compared to a count of stress-days as an indication of stress within the interval. The ratio of stress-days/total-days in the interval was selected as the better measure of moisture stress (M) to be inserted into equation (10). The observation that the ratio was more indicitive of moisture stress points to the need for a detailed record of the duration of the selected intervals of crop development.

The site yield of barley in the moisture stress equation (10) was an average (Y_m) over plots from selected treatments, the aim being that Y_m should represent site yield where nutrient supply was not a limiting factor. Site yields Y_m, duration (days) of intervals of crop development and ratios M' (obtained by procedure 1) and M" (obtained by procedure 2) are presented in Table 22 for the 27 site-years 1959 - 1963.

From the data of Table 22, with Y_m regressed on interval stress ratios M_i, various equations were examined. The analysis showed that moisture stress in only three of the seven intervals contributed significantly to depletion of barley yield: the first, second and fourth intervals. With Y_m regressed on M_1, M_2 and M_4, two equations were obtained:

TABLE 22. Yield (Y_m), total days within 7 growth intervals, and two ratios[a] M' and M" of stress-days/total days for 7 intervals in each of 27 site-years of barley data 1959 - 1963

Site-	Y_m	Number of days per interval							M'							M"						
year	q/ha	1	2	3	4	5	6	7	1	2	3	4	5	6	7	1	2	3	4	5	6	7
0259	32.2	13	12	10	10	13	13	13	0.154	0.083	0.000	0.000	0.692	0.385	0.000	0.154	0.083	0.000	0.000	0.692	0.385	0.000
0359	23.5	14	12	10	10	13	13	13	0.643	0.083	0.200	0.600	0.462	0.231	0.000	0.643	0.083	0.100	0.200	0.462	0.231	0.000
0160	19.1	11	12	11	10	12	12	12	0.000	0.417	0.000	0.300	0.000	0.000	0.000	0.000	0.417	0.000	0.100	0.000	0.000	0.000
0260	22.3	10	12	9	11	13	13	12	0.000	0.583	0.000	0.273	0.000	0.000	0.000	0.000	0.583	0.000	0.091	0.000	0.000	0.000
0360	22.1	12	12	11	11	13	13	12	0.000	0.500	0.000	0.273	0.000	0.000	0.000	0.000	0.500	0.000	0.000	0.000	0.000	0.000
0460	18.7	14	12	12	11	13	13	12	0.929	0.833	0.083	0.273	0.846	0.538	0.083	0.929	0.833	0.167	0.091	0.846	0.538	0.083
0560	17.2	14	12	12	11	13	13	12	0.071	0.750	0.083	0.455	0.846	0.615	0.000	0.071	0.750	0.083	0.545	0.846	0.615	0.000
0361	11.1	11	12	12	12	13	13	13	0.000	1.000	0.917	0.833	0.629	0.000	0.231	0.000	1.000	0.917	0.833	0.629	0.000	0.231
0561	17.0	12	12	14	12	13	13	13	0.917	1.000	0.857	0.500	0.615	0.000	0.000	0.917	1.000	0.857	0.500	0.615	0.000	0.000
0661	10.9	11	12	14	12	13	13	13	0.909	1.000	0.857	0.333	0.615	0.000	0.000	0.909	1.000	0.857	0.333	0.615	0.000	0.000
0761	22.1	11	12	11	11	13	13	12	0.091	0.833	0.000	0.000	0.615	0.462	1.000	0.091	0.833	0.000	0.000	0.615	0.462	1.000
0861	33.2	10	12	10	11	13	13	12	0.000	0.583	0.100	0.091	0.154	0.000	0.167	0.000	0.583	0.000	0.000	0.154	0.000	0.167
0961	36.1	11	12	11	11	13	13	12	0.000	0.667	0.182	0.000	0.385	0.000	0.000	0.000	0.667	0.091	0.000	0.385	0.000	0.000
1061	27.5	12	12	10	11	13	13	12	0.333	0.667	0.200	0.000	0.000	0.000	0.000	0.333	0.667	0.200	0.000	0.000	0.000	0.000
0562	29.7	10	12	10	10	13	13	13	0.000	0.000	0.100	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0762	27.7	9	12	10	10	12	12	12	0.000	0.250	0.600	0.400	0.000	0.000	0.000	0.000	0.250	0.300	0.000	0.000	0.000	0.000
0862	35.8	11	12	11	11	12	12	12	0.000	0.000	0.455	0.000	0.000	0.000	0.000	0.000	0.000	0.182	0.000	0.000	0.000	0.000
0962	33.7	9	12	10	11	13	13	13	0.000	0.333	0.800	0.455	0.000	0.000	0.000	0.000	0.333	0.700	0.273	0.000	0.000	0.000
1062	23.8	9	12	10	11	13	13	13	0.000	0.250	0.700	0.545	0.000	0.000	0.000	0.000	0.250	0.500	0.182	0.000	0.000	0.000
1162	25.9	11	12	9	10	13	13	13	0.000	0.000	0.222	0.400	0.000	0.000	0.000	0.000	0.000	0.111	0.000	0.000	0.000	0.000
1262	32.3	11	12	10	11	13	13	13	0.000	0.000	0.600	0.455	0.000	0.000	0.000	0.000	0.000	0.500	0.182	0.000	0.000	0.000
0563	17.7	10	12	9	11	13	13	13	0.300	0.000	0.889	0.818	0.308	0.769	0.923	0.300	0.000	0.778	0.818	0.308	0.769	0.923
0763	7.2	11	12	9	11	13	13	13	1.000	0.917	1.000	0.727	0.231	0.846	1.000	1.000	0.917	1.000	0.727	0.231	0.846	1.000
0863	7.7	12	12	10	11	13	13	13	0.750	0.833	1.000	1.000	0.846	0.923	0.846	0.750	0.833	1.000	1.000	0.846	0.923	0.846
0963	5.5	11	12	9	11	13	13	13	0.909	0.917	1.000	0.909	0.769	0.846	1.000	0.909	0.917	1.000	0.909	0.769	0.846	1.000
1063	11.8	12	12	9	11	13	13	13	1.000	1.000	1.000	0.818	0.000	0.538	0.692	1.000	1.000	1.000	0.818	0.000	0.538	0.692
1163	21.3	10	12	9	11	13	13	13	0.000	0.000	1.000	0.818	0.000	0.538	0.923	0.000	0.000	0.889	0.818	0.000	0.538	0.923

[a] M' and M" are the ratios obtained by procedures (1) and (2), respectively, described in the text (p. 62).

$$Y_m = 34.7 - 4.7M'_1 - 9.6M'_2 - 15.7M'_4 \qquad (11)$$

and

$$Y_m = 31.4 - 5.4M''_1 - 7.0M''_2 - 13.8M''_4 \qquad (12)$$

where M'_i and M''_i refer to the stress-ratios for the ith growth interval and the superscripts (') and (") refer to procedures (1) and (2), respectively. Addition of one or more ratios of the remaining four intervals to the equation made no significant difference to the regression, where the sequential F-test was used as test criterion. Statistics of the regression by procedures (1) and (2) before elimination (see equation (10)) and for equations (11) and (12) are presented in Table 23.

As stated earlier in this section, these stress equations were developed in order to obtain a site index (W) of moisture stress. The validity of equations (11) and (12) were examined as predictors of yield for the 1964 - 1967 field experiments. Site yields Y_m, duration (days) of intervals of crop development and ratios M' (obtained by procedure 1) and M" (obtained by procedure 2) are presented in Table 24 for the 17 site-years 1964 - 1967. Predictions of Y_m are compared in Table 25. For procedures (1) and (2) the simple correlation coefficients between Y_m and $\hat{Y}_m$ (prediction of Y_m) were 0.600 and 0.736, respectively. Procedure (2) was selected over procedure (1) on the basis of the higher correlation obtained in the prediction of Y_m. Values of W, calculated by the equation:

$$W = 5.4M_1 + 7.0M_2 + 13.8M_4 \qquad (13)$$

are included in the data presented in Table 25.

TABLE 23. Regression coefficients (b_i), standard errors of estimate, partial F-values and R^2 values of moisture stress equations[a] for 27 site-years 1959 - 1963

Variable	b_i	S.E.E. of b_i	Partial F-values[b]	S.E.E.	Overall F-value	R^2
		Equation (10) procedure (1)				
M'_1	-5.75427	3.32173	3.00†			
M'_2	-8.57919	3.16723	7.34*			
M'_3	6.89168	3.98306	2.99			
M'_4	-20.10815	4.95710	16.45**			
M'_5	-1.19888	3.77192	0.10			
M'_6	2.78420	6.79639	0.17			
M'_7	-5.00389	4.65650	1.15			
Intercept	34.01930			4.139	15.07	0.847
		Equation (10) procedure (2)				
M''_1	-8.51430	4.36465	3.81†			
M''_2	-6.39033	3.71268	2.96			
M''_3	9.22146	6.77465	1.85			
M''_4	-22.08078	8.29361	7.09*			
M''_5	0.79660	4.29577	0.03			
M''_6	4.70644	8.63829	0.30			
M''_7	-3.28964	5.30372	0.38			
Intercept	30.16960			4.727	10.92	0.801
		Equation (11)				
M'_1	-4.65574	2.80198	2.76			
M'_2	-9.62282	2.69855	12.72**			
M'_4	-15.73995	2.90466	29.36**			
Intercept	34.73161			4.220	32.25	0.808
		Equation (12)				
M''_1	-5.41335	2.98418	3.29†			
M''_2	-7.04115	2.91279	5.84*			
M''_3	-13.75858	2.91788	22.23**			
Intercept	31.38275			4.541	26.82	0.778

[a] M' and M" are the ratios obtained by procedures (1) and (2), respectively, described in the text (p. 62).

[b] Levels of significance are: ** 0.01
* 0.05
† 0.10

TABLE 24. Yield (Y_m), total days within 7 growth intervals, and two ratios[a] M' and M" of stress-days/total-days for 7 intervals in each of 17 site-years of barley data 1964 - 1967

Site-year	Y_m q/ha	Number of days per interval 1	2	3	4	5	6	7	M' 1	2	3	4	5	6	7	M" 1	2	3	4	5	6	7
0164	19.7	10	11	11	11	15	16	17	1.000	0.091	0.455	0.364	1.000	0.000	0.176	1.000	0.091	0.455	0.455	1.000	0.000	0.176
0165	27.8	14	12	13	11	14	14	14	0.000	0.000	0.462	0.000	0.000	0.000	0.286	0.000	0.000	0.154	0.000	0.000	0.000	0.286
0167	22.9	10	10	11	12	15	8	8	0.000	0.000	0.273	0.583	0.000	0.000	0.000	0.000	0.000	0.000	0.333	0.000	0.000	0.000
0365	25.6	12	12	11	11	14	14	14	0.667	0.000	0.364	0.182	0.000	0.000	0.357	0.667	0.000	0.091	0.000	0.000	0.000	0.357
0367	14.7	15	11	10	12	19	9	10	0.667	0.182	0.400	0.583	0.474	0.000	0.000	0.667	0.182	0.300	0.583	0.474	0.000	0.000
0565	28.8	10	12	11	11	14	14	15	0.000	0.083	0.273	0.000	0.000	0.214	0.867	0.000	0.083	0.077	0.000	0.000	0.214	0.867
0566	19.4	10	12	13	11	13	14	14	0.000	0.000	0.538	0.909	0.077	0.000	0.000	0.000	0.000	0.538	0.909	0.077	0.000	0.000
0567	27.0	15	10	10	14	18	10	7	0.000	0.000	0.000	0.786	0.111	0.000	0.000	0.000	0.000	0.000	0.643	0.111	0.000	0.000
2164	22.5	10	11	12	11	16	17	19	0.200	0.091	0.250	0.909	0.000	0.000	0.368	0.200	0.091	0.000	0.545	0.000	0.000	0.368
2165	28.2	12	12	14	11	14	15	16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2166	30.5	14	13	15	11	14	15	15	0.000	0.615	0.067	0.636	0.000	0.000	0.000	0.000	0.615	0.000	0.273	0.000	0.000	0.000
2167	24.4	14	9	12	14	18	7	10	0.000	0.444	0.167	0.286	0.611	0.000	0.000	0.000	0.444	0.083	0.143	0.611	0.000	0.000
2366	17.8	14	13	15	11	14	14	15	0.714	0.385	0.067	0.455	0.000	0.000	0.000	0.714	0.385	0.000	0.091	0.000	0.000	0.000
2367	27.5	11	14	10	11	20	7	11	0.000	0.214	0.000	0.364	0.200	0.286	0.455	0.000	0.214	0.000	0.091	0.200	0.286	0.455
2565	37.3	11	13	14	11	14	15	16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2566	22.6	13	13	14	11	15	15	15	0.538	0.462	0.000	0.545	0.000	0.000	0.000	0.538	0.462	0.000	0.182	0.000	0.000	0.000
2567	30.4	13	10	11	14	18	7	10	0.000	0.500	0.000	0.357	0.056	0.000	0.600	0.000	0.500	0.000	0.143	0.056	0.000	0.600

[a] M' and M" are the ratios obtained by procedures (1) and (2), respectively, described in the text (p. 62).

TABLE 25. Y_m, two predictions of Y_m (f_1 and f_2)[a] and index of moisture stress (W)[b] for 17 site-years 1964 - 1967

Site-year	Y_m	f_1	f_2	W
0164	19.7	23.4	19.1	12.3
0165	27.8	34.7	31.4	0.0
0167	22.9	25.5	26.8	4.6
0365	25.6	28.7	27.8	3.6
0367	14.7	20.7	18.5	12.9
0565	28.8	33.9	30.8	0.6
0566	19.4	20.4	18.9	12.5
0567	27.0	22.3	22.6	8.8
2164	22.5	18.6	22.2	9.2
2165	28.2	34.7	31.4	0.0
2166	30.5	18.8	23.3	8.1
2167	24.4	25.9	26.3	5.1
2366	17.8	20.5	23.6	7.8
2367	27.5	26.9	28.6	2.8
2565	37.3	34.7	31.4	0.0
2566	22.6	19.2	22.7	8.7
2567	30.4	24.3	25.9	5.5

[a] Prediction f_1 obtained using equation (11), f_2 obtained using equation (12).

[b] Calculation of index (W) by equation (13).

D. Effects of soil moisture stress and soil order on barley response to available nutrients

In the last section evidence was presented that, with nutrients non-limiting, more than 50 per cent of the variation in barley yield was accounted for by moisture stress occurring prior to heading of the crop. Earlier, using equation (7) stated on p. 40, an R^2 value of 0.386 was obtained (see Table 13) in a regression of barley yield on available nutrients (N_A, P_A, N_S, P_S) involving pooled data of the 17 site-years 1964 - 1967. The poor correlation obtained for this regression was not unexpected, since variation in soil moisture conditions for different site-years had not been considered.

With the objective of obtaining a barley yield equation of some value in predicting nitrogen and phosphorus fertilizer requirements for barley, interrelations were examined between variables of equation (7) and two selected site variables: soil order and soil moisture conditions. The dummy variable (T) was used to identify Chernozemic (T = 0) and Luvisolic (T = 1) soils and the site index (W) was used as a measure of moisture stress over the growing season.

Use of coefficients of individual site-year regression equations

The coefficients (b_i) of 17 individual site-year regression equations involving terms N_A, P_A, N_S and P_S are presented in Appendix D. The effects of the independent variables T and W on regression coefficients were examined in a series of 15 regression equations:

(a) $b_0 = z_0 + z'_0T + z''_0W,$

(b) $b_1 = z_1 + z'_1T + z''_1W,$

(c) $b_2 = z_2 + z'_2T + z''_2W,$

. . . .

. . . .

(n) $b_{24} = z_{24} + z'_{24}T + z''_{24}W$ and

(o) $b_{34} = z_{34} + z'_{34}T + z''_{34}W.$

The results of this analysis, presented in Table 26, indicate an influence of T or W on certain variables in equation (7):

(a) Variation in the intercepts (see b_0 in Appendix D) can partly be explained in terms of soil order (T), whereas soil moisture conditions (W) do not contribute significantly to the variability in the b_0's.

(b) Variation in the N_A coefficients (b_1) and in the $N_A{}^2$ coefficients (b_{11}) is partly due to moisture stress (W). In both cases the magnitude of the N_A and $N_A{}^2$ coefficient is reduced by the moisture stress factor.

(c) The variation in the coefficients (see b_{24} in Appendix D) of the interaction of applied and soil phosphorus ($P_A.P_S$) is partly due to having some sites on Chernozemic and other sites on Luvisolic soils.

The interrelations as determined above were considered in the subsequent analyses of the data.

TABLE 26. Regressions of site-year regression coefficients on soil order, T, and moisture stress index, W, giving R^2 and F values

Variable	Regressions of b_i on T and W	R^2	F value[a]
Intercept	$b_0 = 17.5 - 7.5T$	0.187	3.46†
N_A	$b_1 = 0.264 - 0.016W$	0.265	5.43*
$N_A{}^2$	$b_{11} = -(0.00111 - 0.00006W)$	0.274	5.65*
$P_A \cdot P_S$	$b_{24} = 0.00424 - 0.00450T$	0.304	6.55*

[a] Levels of significance are:

*: 0.05 with 1, 15 degrees of freedom
†: 0.10

For completeness it should be pointed out at this stage that in a similar study, Eck and Tucker (1968) compared standard partial regression coefficients (b'_i) rather than the (partial) regression coefficients (b_i), where

$$b'_i = b_i \frac{s_i}{s_y},$$

with s_i and s_y the standard deviations of the ith independent variable and the dependent variable y, respectively. Voss and Pesek (1965), in a greenhouse experiment, compared interrelations between b_i for applied nutrients and soil test values by examining the correlation coefficient matrix adjusted for intercorrelation between soil test values.

Comparison of regression equations involving pooled data

Statistics for five regression equations are presented in Table 27, each equation involving pooled data of the 17 site-years 1964 - 1967. Equations I (see equation (6) and Table 12) and II (see equation (7) and Table 13) were discussed previously. Equation III was obtained by elimination of the non-significant variables P_S^2, $N_A.P_A$ and $P_A.N_S$ from equation II, reducing the number of independent variables in regression from 14 to 11.

Evidence was presented (see Table 26) of interrelations of soil order and soil moisture stress with certain variables which are present in Equation II. To examine this evidence further, barley

TABLE 27. Regression coefficients, F-values, squares of the multiple correlation coefficient (R^2) and standard errors of estimate ($s_{Y.X}$) for five equations involving pooled data of 17 site-years showing the effects of including soil order (T) and moisture stress (W) in the regression

Variable	Regression coefficient	I	II	III	IV	V
N_A	b_1	0.14340**	0.14415**	0.14847**	0.26868**	0.14673**
P_A	b_2	0.18020**	0.18279**	0.18434**	0.18289**	0.17268**
N_S	b_3		0.06035**	0.05695**	0.03737**	0.04271**
P_S	b_4		0.05369**	0.03292**	0.05705**	0.04762**
N_A^2	b_{11}	-0.00077**	-0.00073**	-0.00081**	-0.00135**	-0.00080**
P_A^2	b_{22}	-0.00295**	-0.00212**	-0.00233**	-0.00210**	-0.00241**
N_S^2	b_{33}		-0.00011*	-0.00012*		
P_S^2	b_{44}		-0.00014			
$N_A \cdot P_A$	b_{12}	0.00041*	0.00019			
$N_A \cdot N_S$	b_{13}		-0.00041**	-0.00047**	-0.00043**	-0.00053**
$N_A \cdot P_S$	b_{14}		0.00038**	0.00043**	0.00035**	0.00047**
$P_A \cdot N_S$	b_{23}		-0.00018			
$P_A \cdot P_S$	b_{24}		-0.00083**	-0.00098**	-0.00087**	-0.00090**
$N_S \cdot P_S$	b_{34}		0.00034**	0.00037**		
$N_A \cdot W$	b_{15}				-0.01906**	
$N_A^2 \cdot W$	b_{115}				0.00011**	
T	b_6				-3.83264**	-3.24396**
W	b_5					-0.57071**
Intercept	b_0	16.18130	11.01667	10.21733	13.12377	15.47362
F-value		47.47**	36.00**	45.33**	81.53**	83.06**
R^2		0.227	0.386	0.383	0.549	0.554
$s_{Y.X}$		6.66	5.97	5.33	5.11	4.54

Levels of significance: **: 0.01
*: 0.05

yield (pooled data) was regressed on 18 independent variables, the 14 variables in equation II (applied and soil nutrient terms) and the variables T, $N_A.W$, $N_A^2.W$ and $P_A.P_S.T$. Eliminating terms with non-significant coefficients from the 18-variable regression equation, equation IV was obtained. From Table 27 it is seen that about 55 per cent of the variation in yield (pooled data) was explained by 12 variables in equation IV.

Equation IV is reasonable in an agronomic sense, although from the processes involved in phosphorus uptake by the plant, an interaction between moisture stress and available phosphorus could be expected. Other features of equation IV, including the absence of the linear variable W, suggested the need for further examination of influences of T and W on the regression.

Yield of barley (pooled data) was regressed on 14 variables (applied and soil nutrient terms) and the two linear variables T and W. Equation V was obtained after variables with non-significant coefficients had been eliminated. With 11 variables (including T and W) in the regression, again about 55 per cent of the variation in yield was explained by the regression equation.

From Table 27 it is seen that equations IV and V explain the same percentage of the variation in barley yield for the pooled data of 17 site-years. Equation IV was taken as the final yield equation for the purpose of examining economic aspects of the influence of environmental factors on the response of barley to nitrogen and phosphorus fertilizers.

E. Applications of the barley yield equation

The barley yield equation (Table 27, equation IV) selected in the last section was used to examine several aspects of the economics of fertilizer use in barley production. The main objective in the analyses was to appraise the usefulness of the equation as a predictive model. The equation is presented again for convenience:

$$\begin{aligned} Y = \; & 13.12 - 3.83T + 0.03737N_S + 0.05705P_S + 0.26868N_A \\ & - 0.00043N_A.N_S + 0.00035N_A.P_S - 0.01906N_A.W + 0.18289P_A \\ & - 0.00087P_A.P_S - 0.00135N_A{}^2 + 0.00011N_A{}^2.W - 0.00210P_A{}^2 \end{aligned} \tag{14}$$

It was necessary to first select unit prices for barley (p_Y) and fertilizers (p_N, p_P). The 5-year average price of barley to 1969 was considered relevant: 84¢/bu (= 1.75¢/lb). This price is subject to fluctuations in response to foreign as well as domestic market situations. Selected fertilizer costs were: 10¢/lb for nitrogen and 18¢/lb for phosphorus (8¢/lb P_2O_5). The following price ratios were calculated:

$$p_Y/p_N = 17.50 \text{ kg/q},$$

$$p_Y/p_P = 9.72 \text{ kg/q and}$$

$$p_P/p_N = 1.80.$$

To examine the effect of changing price ratios on optimal fertilizer inputs, other prices were considered. The price ratios:

$$p_Y/p_N = 15.75 \text{ kg/q and}$$

$$p_Y/p_P = 8.75 \text{ kg/q}$$

are 10 per cent lower than the price ratios calculated above and represent either (a) an increase in the price of barley or (b) a decrease in the cost of fertilizer.

Equation (14) describes the influence of moisture stress (W) on the response of barley to applied nitrogen (N_A). The nature of this interrelation is illustrated in Figure 2 for two levels of N_A as W increases from 0 to 20. It was convenient to postpone until later a more detailed examination and discussion of the moisture stress index. To examine other variables in the yield equation isolated from variations in W, a value of 5.0 was assigned to the index. This value of W is considered appropriate to the situation where soil moisture conditions are good at seeding, followed by average amounts of rainfall normally distributed.

Calculation of optimal fertilizer inputs

The effects of soil test values and input - output prices on optimal fertilizer inputs were determined by calculations based on equation (14). The marginal products (MP) per unit of N_A and P_A were obtained as the first derivatives of equation (14), thus:

$$MP_{N_A} = 0.26868 - 0.00270N_A - 0.00043N_S + 0.00035P_S - 0.01906W + 0.00022N_A.W \qquad (15)$$

and

$$MP_{P_A} = 0.18289 - 0.00087P_S - 0.00420P_A. \qquad (16)$$

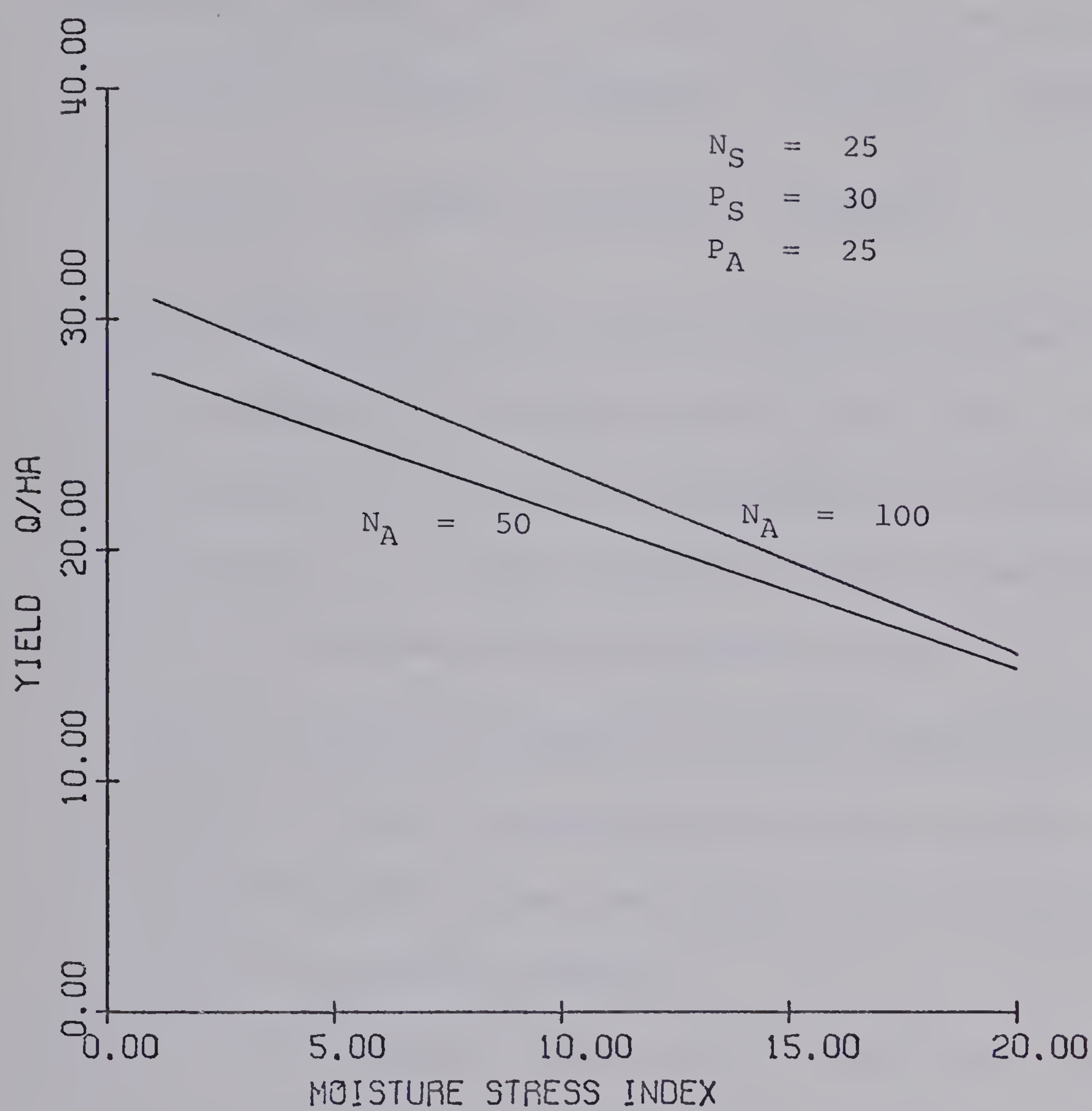


Figure 2. Effect of the moisture stress index (W) on barley yield for two inputs (kg/ha) of nitrogen fertilizer (N_A).

Assuming a stress index (W) of 5.0, equation (15) reduced to:

$$MP_{N_A} = 0.17338 + 0.00035P_S - 0.00043N_S - 0.00160N_A. \qquad (17)$$

Setting MP_{N_A} and MP_{P_A} equal to appropriate inverse price ratios:

$$p_N / p_Y = 0.17338 + 0.00035P_S - 0.00043N_S - 0.00160N_A \qquad (18)$$

$$p_P / p_Y = 0.18289 - 0.00087P_S - 0.00420P_A. \qquad (19)$$

Equations (18) and (19) were used to calculate optimal inputs of N and P at different price ratios and soil test values. Calculated optimal inputs were compared to recommendations of the provincial soil testing service. The data presented in Table 28 indicate:

(a) At low N_S levels, calculated optimal inputs of N_A compare favourably to inputs recommended by the soil testing service. At a N_S level of 28 kg/ha (an average situation) calculated optimal input is approximately 44 per cent higher than that presently recommended by the soil testing service.

(b) Calculated optimal inputs of P_A are about 30 per cent lower than recommendations of the soil testing service.

(c) As inputs become 10 per cent cheaper relative to output, optimal inputs increase but the ratio of fertilizers is changed.

For certain situations the optimal inputs compare poorly to recommendations of the soil testing service. However, the opinion is held by some that recommendations of the soil testing service underestimate the nitrogen requirement and overestimate the phosphorus requirement. The calculated data lend qualified support for this body of opinion

TABLE 28. Comparison of fertilizer recommendations by the provincial soil testing service and calculated optimal fertilizer inputs for barley production, showing the effects of soil test values and price ratios on the inputs calculated using equation (14)[a]

Inverse price ratios (q/kg)		Soil test values (kg/ha)		Barley yield	Optimal fertilizer inputs (kg/ha)			
					Calculated equation (14)		Soil test service	
p_N/p_Y	p_P/p_Y	N_S	P_S	q/ha	N	P	N	P
0.05714	0.10286	0	34	26.00	80	12	78	17
0.05714	0.10286	112	34	27.51	50	12	6	17
0.05714	0.10286	28	34	25.67	72	12	50	17
0.05714	0.10286	28	0	23.60	72	19	50	24
0.05714	0.10286	28	112	31.50	72	0	50	7
0.05143	0.10286	0	34	26.22	84	12	78	17
0.05143	0.10286	112	34	27.90	54	12	6	17
0.05143	0.10286	28	34	25.89	76	12	50	17
0.05143	0.10286	28	0	23.77	76	19	50	24
0.05143	0.10286	28	112	31.86	76	0	50	7
0.05143	0.09257	0	34	26.34	84	15	78	17
0.05143	0.09257	112	34	27.02	54	15	6	17
0.05143	0.09257	28	34	26.01	76	15	50	17
0.05143	0.09257	28	0	23.80	76	22	50	24
0.05143	0.09257	28	112	31.86	76	0	50	7

[a] Calculations made with stress index constant at 5.0. Yield calculations (T = 0) are for Chernozemic soils.

and indicate the magnitude of the difference. The observed effects of changes in price ratios on fertilizer inputs appear reasonable.

Fertilizer inputs below optimal levels

Farm credit facilities in the Province of Alberta are such that the situation of limited capital for resource allocation is seldom a problem influencing input of fertilizers for cereal production. However, it is not an uncommon practice for fertilizers to be used at levels below that which is recommended. This practice is based on the uncertainty of product price and the risk of drought. Also, it is supported by some workers on the premise that marginal products are much higher at lower input levels. It was decided to test the barley yield equation by an examination of this aspect of fertilizer use.

The isocline equation or least-cost expansion path was calculated by setting MP ratios equal to their inverse price ratios, thus from equations (18) and (19):

$$\frac{p_N}{p_P} = \frac{0.17338 + 0.00035P_S - 0.00043N_S - 0.00160N_A}{0.18289 - 0.00087P_S - 0.00420P_A} \qquad (20)$$

In Figures 3 and 4 isoquants and isoclines are presented for several soil test (N_S, P_S) situations, where W, p_N and p_P were held constant at 5.0, 10¢/lb and 18¢/lb, respectively. Equation (14) was used to calculate the isoquants and equation (20) was used to calculate the isoclines. To indicate the region of economic interest, yield (Y_{OPT}) at optimal inputs of N_A and P_A is shown on each diagram, calculated

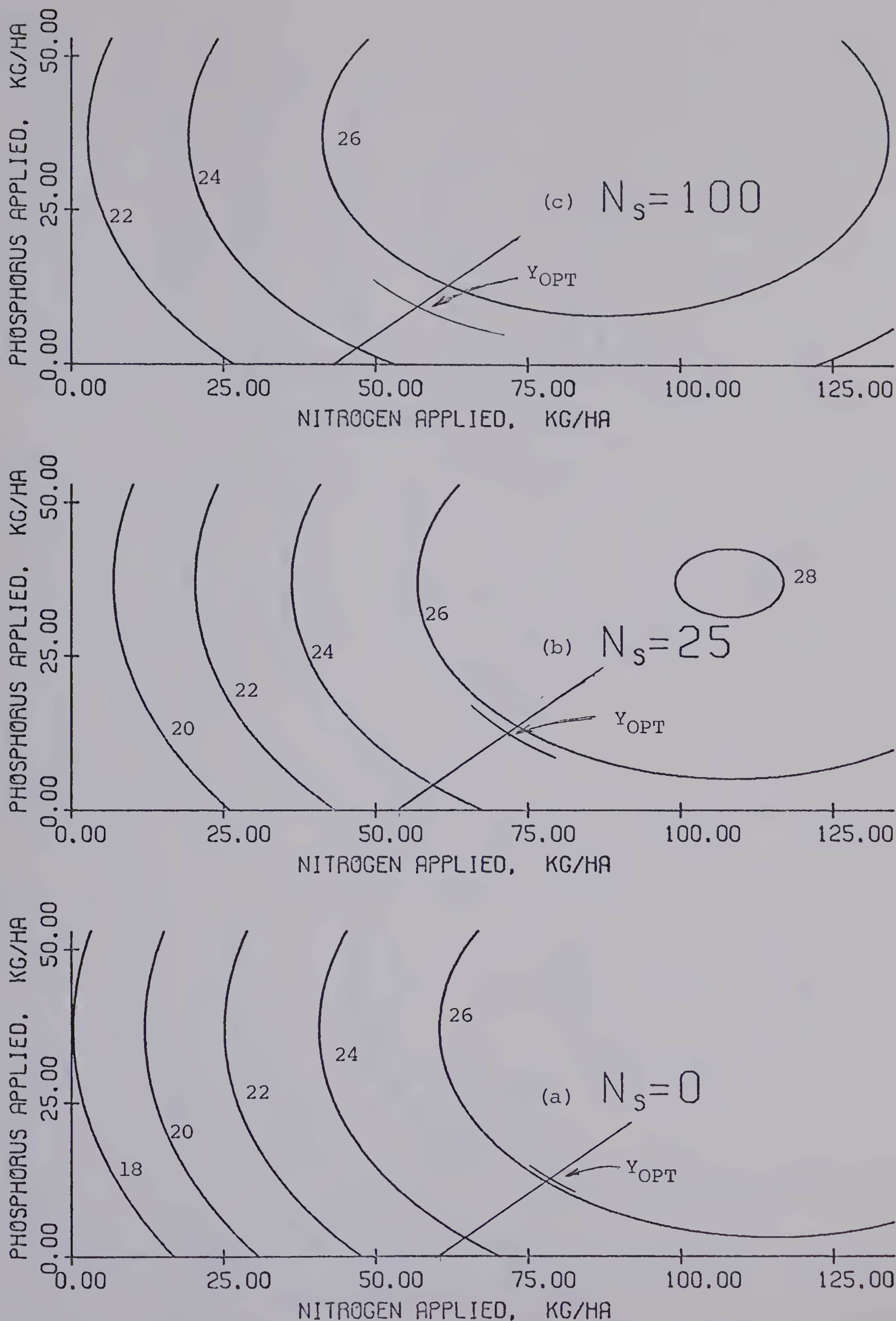


Figure 3. Isoquant-isocline diagrams, showing optimum barley yield (Y_{OPT}) for three nitrogen soil test (N_S) levels. Variables held constant: W = 5.0, P_S = 30, p_Y = 175, p_N = 10 and p_P = 18.

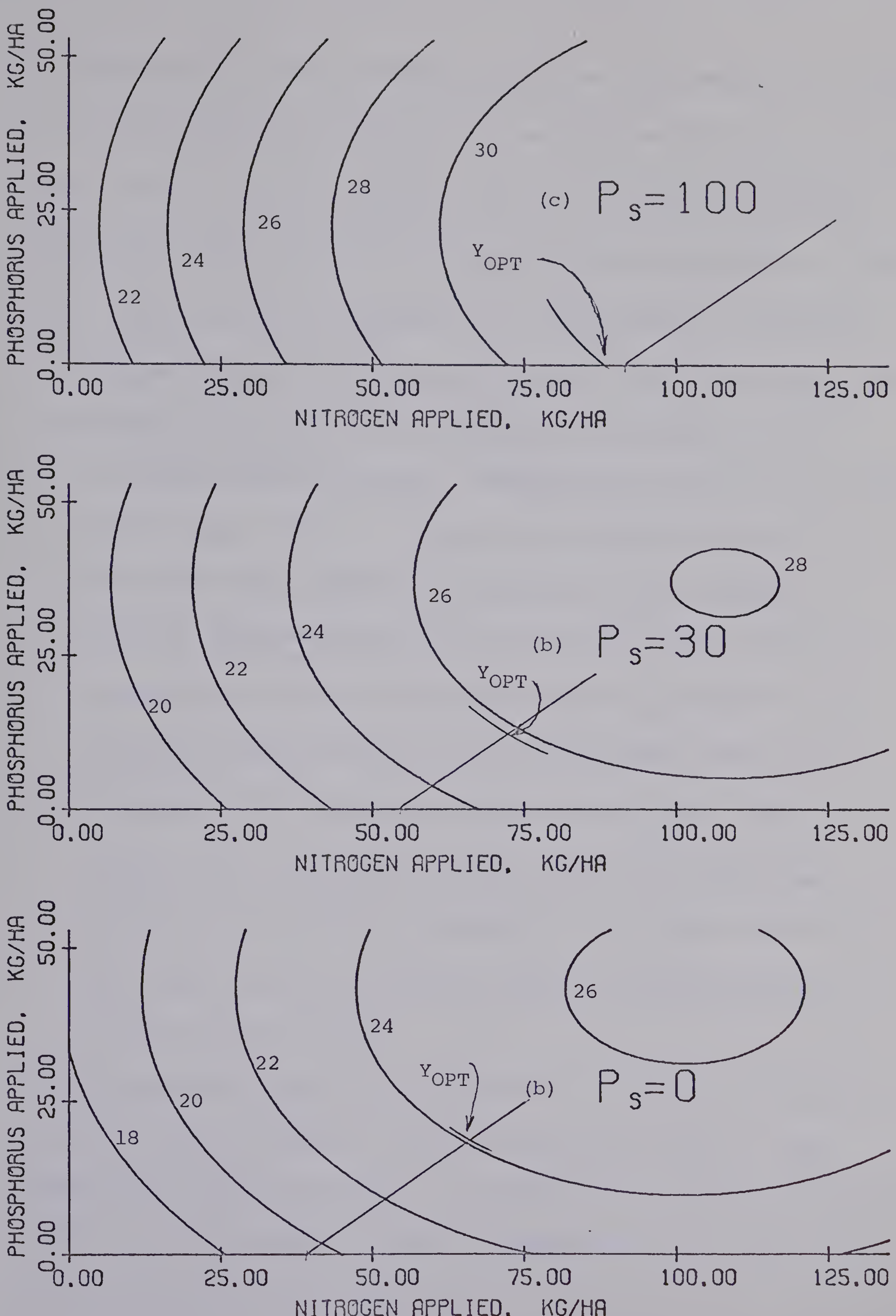


Figure 4. Isoquant-isocline diagrams, showing optimal barley yield (Y_{OPT}) for three phosphorus soil test (P_S) levels. Variables held constant: $W = 5.0$, $N_S = 25$, $p_Y = 175$, $p_N = 10$ and $p_P = 18$.

by equations (14), (18) and (19) where p_Y was held constant at 1.75¢/lb. In the three diagrams of Figure 3, P_S was assigned the value of 30 and three levels of N_S were compared: (a) 0, (b) 25 and (c) 100 kg/ha. In the three diagrams of Figure 4, N_S was assigned the value of 25 and three levels of P_S were compared: (a) 0, (b) 30 and (c) 100 kg/ha. The isoquant and isocline diagrams of Figures 3 and 4 illustrate certain features of equation (14) including the following:

(a) At certain levels of output, isoquants may intersect one or both of the axes. This is a feature of the quadratic form.

(b) Soil test values influence the geometry of the isoquants. Figure 3 indicates that, with P_A at 0 and P_S held at 30, a barley yield of 22 q/ha can be attained at N_S values of 0, 25 and 100 by inputs of N_A at 47, 43 and 27 kg/ha, respectively.

(c) Isoclines in each situation intersect the N_A-axis. This feature is of considerable economic importance because the proportions of N_A and P_A recommended at the optimal level of fertilizer use do not represent least-cost combinations for levels below the optimal.

The relationships implied by the isoquants and isoclines of Figures 3 and 4 are based on equation (14) and relevant price data. These relationships appear reasonable. If desired, the isocline equation (20) could be used to provide fertilizer recommendations for inputs below the optimal level of fertilizer use.

Applications of the stress index (W)

The bulletin containing general fertilizer recommendations for soils of central and northern Alberta, published by the Alberta Department of Agriculture (1968) remarks on the influence of soil moisture conditions on the economics of fertilizer use:

> ". . . The amount of soil moisture at seeding, the amount and distribution of rainfall during the growing season, growing season temperatures, availability of other soil nutrients and previous crop and soil management will, to a great extent, affect the economy of fertilizer use. . ."

The moisture stress index can be used to modify optimal fertilizer recommendations to account for soil moisture conditions prior to seeding. In selecting a value of W relevant to moisture conditions in the spring, the evidence examined in calculating the moisture stress equation provided useful guidelines:

(a) Amounts and distribution of average rainfall and evaporative demand are such that short periods of moisture stress will normally be encountered from planting to heading, even under the situation of good spring moisture conditions.

(b) Soil moisture conditions at seeding were observed to influence the incidence of moisture stress in the "critical" stage from jointing to heading of the crop.

The values assigned to W were 5.0 for good spring moisture conditions and 10.0 for poor spring moisture conditions assuming in each case a normal seasonal rainfall pattern. A refinement in the prediction of W should involve an analysis of the risk of drought, a study beyond the scope of this investigation.

The effect of a selected value of W on the optimal fertilizer input is shown in Table 29. The value of W influences the recommended input of nitrogen fertilizer, but not of phosphorus fertilizer. Given the situation of poor soil moisture conditions at time of seeding, the nitrogen recommendation is reduced about 45 per cent from that recommended when soil moisture conditions are good. The isoquant-isocline diagrams presented in Figure 5 further illustrate these relationships. As W increases, the distance between isoquant lines also increase and curvature of the isoquants change such that, at higher predictions of W, larger fertilizer inputs are required to attain a specified yield. A comparison of isoclines of the three diagrams (where the variables N_S and P_S are held constant) indicates an influence of W on the least-cost combinations of nitrogen and phosphorus inputs.

The remarks quoted above from the bulletin on general fertilizer recommendations regarding the influence of soil moisture conditions on the economy of fertilizer use are supported by the foregoing discussion.

TABLE 29. Effect of selected stress index (W) on optimal fertilizer input[a]

Assigned moisture stress index	Optimal fertilizer input (kg/ha)	
	Nitrogen	Phosphorus
0.0	78	13
1.0	78	13
2.0	77	13
3.0	76	13
4.0	74	13
5.0	72	13
6.0	70	13
7.0	67	13
8.0	63	13
9.0	55	13
10.0	41	13
11.0	6	13

[a] Calculations based on equation (14), variables held constant: N_S = 25, P_S = 30, p_Y = 175, p_N = 10 and p_P = 18.

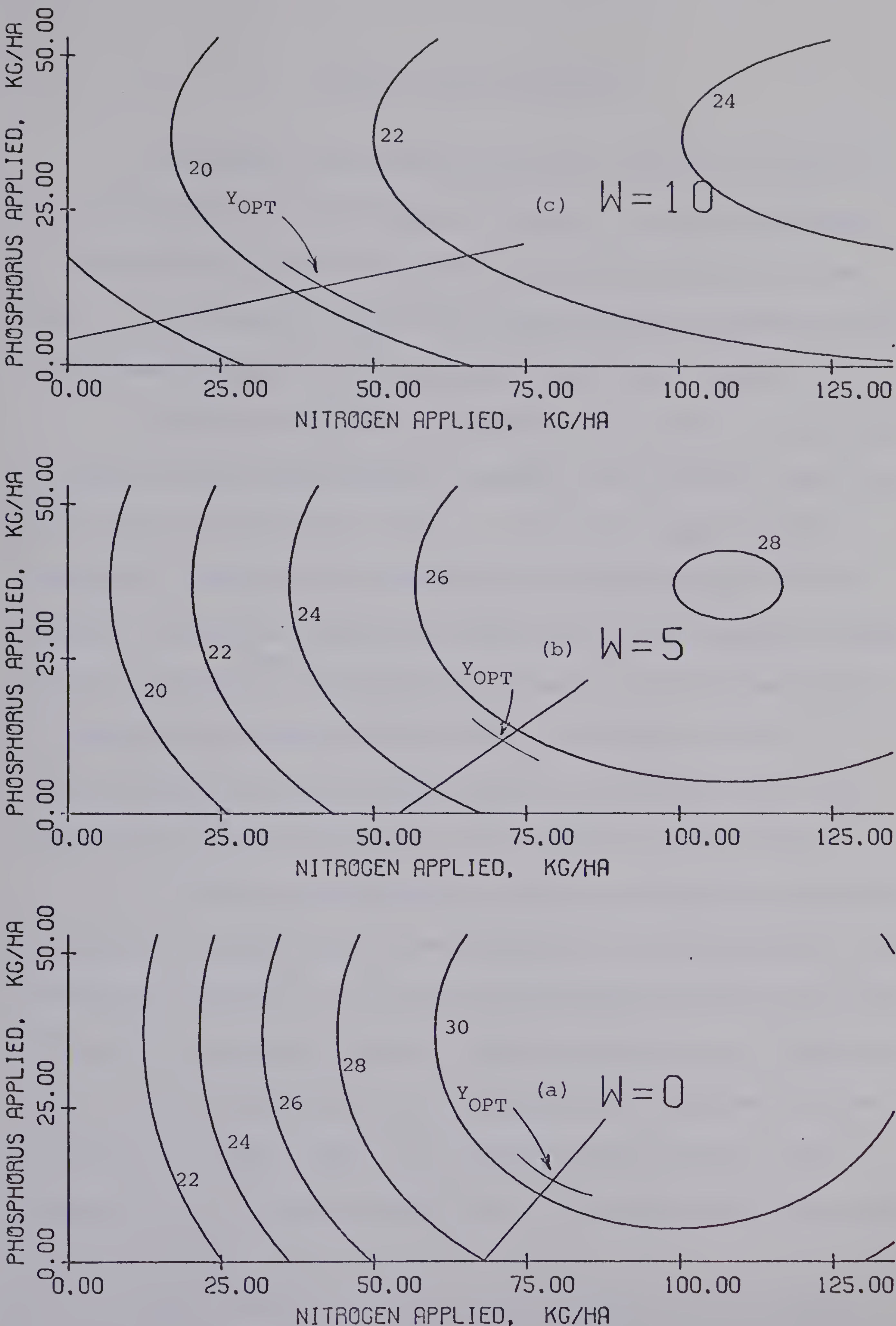


Figure 5. Isoquant-isocline diagrams, showing optimum barley yield (Y_{OPT}) at three levels of moisture stress (W). Variables held constant: N_S = 25, P_S = 30, p_Y = 175, p_N = 10 and p_P = 18.

SUMMARY AND CONCLUSIONS

Fertilizers have recently attained considerable importance in crop production in the province of Alberta. In 1968, investment in fertilizers exceeded $30,000,000, a six-fold increase within one decade. In the same year about 5,000 Alberta farmers obtained fertilizer recommendations from the provincial soil testing service.

General fertilizer recommendations for soils of the province are based on more than 40 years of research into fertilizer use, combining field and laboratory studies. The Alberta Department of Agriculture established a provincial soil testing service in 1955. Emphasis in fertilizer research was then directed to the many problems related to fertilizer recommendations based on soil test evaluation. The importance of amount and distribution of seasonal rainfall to fertilizer response was the major problem encountered in collating evidence over sites and seasons of crop responses to fertilizers.

In 1964 an interdisciplinary research project was undertaken to study the response patterns and economics of fertilizer use in cereal and forage production as influenced by available nutrients in the soil and certain environmental factors. Field experiments were conducted in central Alberta at three locations on Chernozemic soils and at three locations on Luvisolic soils. The results reported here are for Gateway barley, the selected cereal crop. The main objectives of this examination were:

(a) to develop a method for assessing the effect of soil moisture stress on yield and response to fertilizers of barley grown under dryland conditions and

(b) to derive a generalized yield equation relating yield of barley grown on stubble to rates of applied fertilizers, soil test levels, moisture stress and soil grouping and to examine the economic implications.

To study the response of barley to three fertilizer nutrients, nitrogen, phosphorus and potassium, each at five levels, a central composite design was used with 23 treatment combinations in each of two replicates. A fertilizer treatment, applied annually at time of seeding, was assigned to each plot. Prior to seeding and after harvesting, soil samples were collected from each plot for moisture analysis and soil testing. Certain daily meteorological observations were recorded at each site. Sites were visited at regular intervals and stages of crop development were recorded.

Analyses of variance on data of 17 individual site-years indicated the N and P treatments produced significant effects on barley yields, whereas the effect of K was not significant. The lack of significant effects of applied nutrients at site 21 could be attributed to the high soil nutrient status of this one Chernozemic soil.

Regression analyses were carried out on the relationship of yield of barley (Y) to applied nitrogen (N_A) and phosphorus (P_A) using a second-order polynomial model. For the regression involving pooled data of the 17 site-years, regression coefficients of linear and quadratic terms were significant at the 1 per cent level and the regression coefficient of the interaction $N_A.P_A$ was significant at the

5 per cent level. The square of the multiple correlation coefficient (R^2) for this regression was 0.227.

Using the second-order polynomial model, regression analyses were carried out on the relationship:

$$Y = f(N_A, P_A, N_S, P_S),$$

where the additional terms N_S and P_S represent soil test values for nitrate-nitrogen and available phosphorus, respectively. The value of N_S represents nitrate-nitrogen of the soil to a depth of 24 inches (61 cm) and the value of P_S represents available phosphorus to a depth of 6 inches (15.2 cm). A regression equation was obtained involving pooled data of the 17 site-years where the non-significant variables P_S^2, $N_A.P_A$ and $P_A.N_S$ were eliminated by a forward selection procedure. With eleven variables retained in the regression, the R^2 value was 0.383.

Data external to this investigation were used to derive an equation relating yield of barley to moisture stress occurring within three stages of crop development: (1) planting to emergence, (2) emergence to onset of tillering and (3) jointing to heading. Moisture stress analysis was based on a computed daily soil moisture budget for each site. The moisture stress equation was used to calculate a moisture stress index (W) for each of the 17 site-years.

For pooled data of the 17 site-years a yield equation was obtained relating yield to applied and soil nutrients (N_A, P_A, N_S, P_S), the stress index (W) and soil order (T). The term W was introduced

into regression as an interaction with applied nitrogen ($N_A.W$, $N_A{}^2.W$), whereas T was introduced as a linear variable. With 12 variables in the regression, the R^2 value was 0.549. This yield equation was applied to an examination of several aspects of the economics of fertilizer use.

The following conclusions can be drawn from the evidence presented:

(a) The prediction of nitrogen fertilizer requirement is significantly improved by evaluation of nitrate-nitrogen in the soil to a depth of 12 or 24 inches over evaluation to a depth of 6 inches (15.2 cm).

(b) With nutrients non-limiting, about 55 per cent of the variation in yield of barley observed in central Alberta can be explained by moisture stress occurring prior to heading of the crop.

(c) The response surface of nitrogen and phosphorus fertilizers applied to barley for the three Luvisolic soils was very similar to that of the three Chernozemic soils. This evidence supports procedures of the soil testing service in evaluating fertilizer requirements of these soils in central Alberta.

(d) A favourable change in product price increases optimal inputs, but the optimal fertilizer combination is changed.

(e) At low soil test values of N the calculated optimal input of fertilizer N agrees closely with recommendations of the soil testing service. At a soil test value of 25 kg/ha the calculated optimal input is 44 per cent higher than that recommended.

(f) Calculated optimal inputs of fertilizer P are about 30 per cent lower than recommendations of the soil testing service.

(g) The ratio of N to P recommended at the optimal level of fertilizer input is often not the least-cost combination of N and P for fertilizer inputs below the optimal level.

(h) Based on predicted values of W, given the situation of poor soil moisture conditions at time of seeding the calculated optimal input of fertilizer N is reduced about 40 per cent from that calculated for good soil moisture conditions. This evidence supports general fertilizer recommendations for cereal crops in central Alberta.

Further examination of the data is recommended with reference to interactions of W and T with other variables in regression and also the usefulness of a linear W variable in the regression.

The usefulness of the moisture stress index (W) in predicting fertilizer requirements could be much improved by related drought risk analyses for selected soil moisture conditions at time of seeding.

Gateway barley was selected as the test variety for this project mainly upon the characteristic of early-ripening. While Gateway barley was a widely recommended variety at the time of selection, it is now generally considered "low-yielding" in central Alberta and concomitant studies should be examined to relate the evidence obtained here to varieties which are commercially more significant.

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APPENDIX A. YIELD OF BARLEY (q/ha) FOR 1964-1967 SITES

PLOT TMT. NO.	0164		0165		0166		0167		0365		0367		0565		0566		0567	
	replicate																	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	18.3	13.1	30.2	26.4	18.5	20.9	17.8	20.5	20.7	17.0	18.3	13.9	24.5	23.4	18.4	16.6	21.4	23.2
2	21.6	12.4	27.4	31.6	26.1	24.1	19.3	22.6	17.9	22.4	15.0	14.4	23.6	23.5	16.9	19.7	24.5	24.4
3	20.9	18.3	33.9	28.3	31.7	20.2	22.5	21.6	24.6	24.2	17.8	10.3	27.3	22.1	17.1	19.3	22.0	23.6
4	19.6	20.9	33.2	29.2	27.6	18.8	25.0	20.5	20.2	24.4	17.6	13.8	28.1	21.6	21.3	16.2	24.3	20.3
5	18.9	15.0	30.8	30.7	32.7	18.8	25.0	22.0	17.9	19.9	10.0	12.2	30.1	33.2	22.1	22.8	25.3	27.1
6	15.7	15.0	32.5	29.3	24.1	20.9	20.8	19.8	20.7	22.7	11.0	15.7	32.7	32.4	19.9	21.7	28.4	28.3
7	20.3	21.6	32.0	29.7	27.9	27.9	23.7	25.4	32.9	29.1	17.0	15.8	33.6	33.9	24.3	15.2	29.1	25.2
8	18.9	20.3	31.2	23.6	44.2	25.4	25.4	22.1	27.0	25.2	18.3	16.0	26.0	31.4	23.0	22.7	31.4	30.2
9	22.2	14.3	30.6	28.2	30.7	22.3	28.3	25.6	27.4	26.0	18.4	17.1	27.3	25.6	25.2	16.5	26.7	29.6
10	22.8	18.3	29.5	18.4	30.4	16.4	24.1	16.6	11.8	13.9	12.9	12.4	19.5	11.5	12.5	12.4	19.8	15.3
11	20.9	17.7	29.5	27.6	25.4	24.1	26.4	17.6	27.9	25.8	14.2	17.5	32.1	28.2	19.5	19.5	32.5	29.7
12	15.7	13.1	21.3	22.0	20.6	14.7	17.5	13.0	15.2	14.7	6.6	6.2	24.6	24.9	16.5	18.3	24.1	21.5
13	20.9	21.6	29.8	29.9	41.1	18.8	27.3	24.2	27.2	30.2	14.8	15.0	32.7	32.1	13.8	21.8	27.4	30.8
14	18.9	18.9	29.1	28.7	26.9	19.8	24.0	22.8	21.7	27.7	12.9	15.9	25.1	26.2	17.7	15.3	25.6	25.1
15	23.5	17.0	29.2	26.9	36.6	26.1	29.0	23.6	23.0	24.9	17.8	16.6	33.5	22.0	17.9	22.4	28.6	25.5
16	11.8	11.8	19.7	21.8	13.2	14.7	13.3	12.5	15.5	14.7	9.3	8.5	14.1	13.4	12.4	10.0	17.8	13.0
17	27.4	20.9	17.7	20.9	17.0	18.1	16.4	14.8	15.7	12.7	15.8	12.4	15.2	10.9	11.2	10.0	14.9	16.4
18	18.9	17.0	26.0	21.4	25.1	17.0	19.5	16.2	14.0	14.7	15.9	13.4	18.4	18.6	12.5	12.3	18.8	15.7
19	9.2	10.4	18.7	19.6	15.3	14.7	12.0	16.0	14.2	14.7	7.5	8.6	30.1	22.8	11.0	10.2	22.7	22.8
20	10.4	11.1	25.4	25.0	19.8	18.8	15.9	17.9	17.9	13.9	9.2	9.6	31.1	17.1	16.7	15.3	27.0	29.2
21	22.8	19.6	26.0	26.2	34.8	16.0	21.8	19.6	29.2	25.3	16.5	13.9	25.0	17.5	22.8	20.3	28.0	32.4
22	23.5	22.2	20.9	28.1	35.2	31.4	25.8	27.9	24.1	30.4	16.5	15.9	21.2	30.1	21.7	22.1	28.1	30.6
23	12.4	9.2	23.5	16.9	16.4	14.3	12.8	12.1	13.4	13.3	11.2	8.6	13.6	13.6	10.8	11.3	15.9	15.7
24	12.4	11.1	20.2	17.4	21.6	14.3	14.1	10.8	15.5	16.4	9.6	11.2	16.6	10.4	12.3	7.3	14.9	13.3

APPENDIX A. (continued)

PLOT TMT.	2164		2165		2166		2167		2365		2366		2367		2565		2566		2567	
	replicate																			
NO.	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2
1	21.4	27.0	30.0	29.0	27.8	34.4	27.1	28.3	17.6	11.8	14.0	12.0	29.8	30.1	22.0	30.1	17.1	11.9	34.6	34.2
2	25.4	27.0	31.6	26.8	13.1	37.5	27.9	21.8	16.0	18.0	15.0	10.1	28.2	31.4	18.3	15.0	15.1	20.3	29.6	33.7
3	23.6	21.4	31.7	28.7	27.1	29.9	25.9	26.4	20.6	15.0	15.0	11.3	29.6	33.8	21.1	35.2	18.3	23.7	28.8	31.1
4	27.6	23.9	31.5	30.2	24.0	38.5	27.1	24.0	15.1	24.0	16.9	6.6	29.7	32.5	20.8	22.5	15.1	13.4	30.9	26.1
5	20.4	18.0	29.1	23.0	31.5	27.3	25.8	22.4	16.0	15.3	19.3	21.2	26.9	28.6	32.1	43.7	18.6	24.9	35.5	33.0
6	19.8	21.3	25.3	27.1	28.7	35.7	28.6	25.2	19.4	18.0	16.8	22.4	29.8	29.7	36.6	37.9	21.5	23.1	31.8	28.3
7	24.2	26.7	32.3	12.5	30.6	39.0	26.8	29.5	18.8	19.3	16.8	13.4	24.5	31.0	36.1	23.6	29.2	17.1	26.4	33.8
8	24.3	23.4	29.0	29.7	30.5	44.6	26.7	21.6	20.6	25.6	16.0	16.8	30.7	27.3	33.7	39.2	22.5	22.1	35.5	32.3
9	22.6	22.3	32.4	33.6	27.9	29.3	25.2	27.2	17.7	15.9	16.8	17.0	27.0	26.9	35.2	33.7	23.0	23.2	34.2	31.1
10	20.7	25.1	34.5	23.5	26.0	25.8	23.2	23.9	9.7	10.2	11.1	12.3	26.0	20.4	11.9	22.2	8.2	14.1	12.7	27.6
11	20.4	21.4	31.2	29.0	24.5	36.5	23.3	22.2	16.5	17.8	17.8	19.2	29.8	34.0	42.9	32.8	25.9	25.6	36.2	32.7
12	17.9	19.9	29.7	27.0	38.1	38.6	26.0	28.2	12.4	10.8	14.0	14.3	19.5	20.2	25.1	34.2	17.9	19.9	34.7	30.5
13	26.0	23.2	30.5	30.2	30.9	30.8	28.4	26.4	24.0	18.5	16.8	10.9	29.9	30.1	30.2	37.2	24.3	25.6	30.8	32.1
14	25.9	25.2	35.5	31.0	28.8	28.2	25.6	23.2	23.3	17.6	18.7	16.9	30.2	28.6	18.7	41.2	24.2	26.2	35.4	36.1
15	19.6	29.5	27.2	29.6	27.7	41.3	16.1	31.5	28.8	23.0	23.5	14.2	28.2	29.0	30.9	26.7	19.9	23.9	30.1	35.6
16	20.7	20.9	22.6	23.2	41.3	29.6	18.6	16.1	12.8	7.2	10.4	8.1	19.2	23.4	13.8	16.0	13.7	14.3	14.3	20.6
17	20.5	23.7	31.8	28.0	21.2	29.5	18.9	18.0	7.7	4.6	9.9	6.0	20.5	19.2	8.0	10.1	5.8	7.8	10.4	16.5
18	18.6	21.5	25.6	26.4	18.4	28.3	22.2	23.1	13.3	10.0	17.4	6.8	18.7	22.5	11.4	10.9	9.6	8.3	6.9	17.6
19	19.4	20.3	25.5	30.4	32.3	39.1	21.6	24.2	13.3	8.5	26.0	17.4	24.4	20.7	35.1	45.0	24.3	22.8	22.8	35.7
20	18.9	25.0	24.8	21.1	30.0	29.1	17.9	23.0	15.9	8.4	19.3	12.0	21.7	21.3	39.4	37.6	24.2	21.3	28.0	33.3
21	24.3	18.1	26.3	17.6	37.7	29.9	19.5	19.7	24.5	18.1	16.5	17.5	32.0	31.7	38.9	43.1	22.7	22.7	26.7	31.5
22	20.9	24.8	29.6	27.6	27.0	35.4	26.4	21.1	18.9	18.5	16.7	16.5	30.7	26.7	38.2	46.8	24.3	25.5	30.8	34.4
23	18.1	19.0	27.1	13.0	19.3	35.1	19.3	17.8	9.5	5.4	11.2	9.3	18.9	18.1	16.1	13.6	16.4	13.0	21.3	18.6
24	18.6	27.2	21.2	19.5	30.0	41.1	23.2	21.3	10.3	11.3	10.6	10.3	19.4	18.7	9.6	9.3	9.2	13.3	9.9	17.6

APPENDIX B. NITROGEN, PHOSPHORUS AND POTASSIUM ANALYSES AND SOIL MOISTURE DATA OF 1964-1967 SITES[a,b,c]
(Two replicates arrayed by plot treatments, samples collected prior to seeding.)

SITE-YEAR & TMT. NO.	nitrate-N (lb/a)								available-P (lb/a)				exchangeable-K (lb/a)				soil moisture per cent (oven-dry basis)							
	0-6"		6-12"		12-24"		24-36"		0-6"		6-12"		0-6"		6-12"		0-6"		6-12"		12-24"		24-36"	
0164																								
1	43	52	45	43	26	32	22	22	6	6	3	4	204	236	250	252	24.3	26.2	21.7	23.0	16.7	17.5	18.4	18.1
2	27	27	38	45	32	36	32	32	6	16	1	1	236	264	216	308	30.0	25.0	30.0	22.6	18.1	15.9	17.6	16.2
3	27	38	50	40	26	26	26	26	8	6	2	1	196	228	238	372	26.2	26.7	25.9	18.5	16.5	15.1	18.2	17.0
4	40	19	45	34	26	26	26	22	11	7	2	3	264	236	288	264	27.9	27.8	22.9	23.1	16.4	16.0	17.4	18.1
5	38	40	47	20	32	22	26	22	9	8	2	6	236	236	224	248	25.8	27.9	25.0	23.3	15.3	17.0	17.0	18.9
6	29	18	47	43	32	26	32	22	7	8	2	3	206	230	328	286	26.8	28.0	21.4	24.8	16.6	16.7	18.0	18.6
7	27	18	47	38	32	22	26	26	7	6	1	3	216	236	248	304	25.7	27.4	24.4	23.2	16.7	17.6	17.9	18.2
8	22	36	52	27	32	26	22	26	5	4	0	0	178	218	208	282	25.4	26.6	26.0	21.0	15.7	15.1	17.6	16.5
9	22	27	22	20	72	26	32	26	6	8	0	4	274	250	296	252	24.8	23.5	23.9	22.6	16.9	15.4	17.9	16.4
10	20	16	67	20	26	36	26	22	11	5	1	3	224	230	262	238	28.4	29.2	26.9	27.3	17.2	17.0	17.5	15.8
11	34	38	34	36	32	32	32	26	9	20	3	3	236	236	262	256	27.2	26.9	23.0	19.8	16.3	15.3	18.6	15.3
12	13	16	22	29	36	32	32	26	11	6	3	0	264	238	232	268	28.0	28.6	28.7	25.7	18.8	17.3	18.4	19.9
13	45	34	54	31	22	22	26	26	5	6	0	1	204	260	198	306	25.1	25.1	23.6	20.3	14.8	16.1	18.5	20.2
14	27	19	47	47	26	32	26	22	8	4	1	2	244	286	290	356	25.9	23.4	22.0	21.0	15.9	16.5	18.0	16.1
15	43	38	50	31	32	32	26	26	8	6	0	4	216	236	252	306	26.7	26.7	23.7	20.8	15.5	15.3	15.7	19.0
16	18	27	31	22	22	26	22	22	9	8	3	4	252	218	260	252	26.1	28.3	24.8	25.6	17.0	16.6	18.5	20.1
17	19	20	22	27	32	22	26	22	5	4	1	2	230	240	230	232	32.6	27.0	29.2	25.5	19.8	16.7	20.2	18.4
18	56	18	61	40	32	22	22	22	6	7	0	1	186	236	206	238	27.7	24.2	24.9	21.6	14.8	14.2	17.0	13.9
19	36	22	40	27	36	32	26	26	8	6	5	4	256	218	282	316	25.6	28.0	23.8	22.2	15.9	16.2	18.8	17.9
20	18	38	29	27	26	26	26	26	8	4	4	6	230	280	230	300	26.6	25.9	27.3	22.6	16.2	16.5	18.3	17.9
21	22	45	45	22	26	26	26	32	8	5	2	0	230	280	268	372	24.6	27.2	23.4	22.6	16.3	15.4	18.7	17.2
22	45	54	38	47	32	32	22	32	8	7	5	1	208	280	248	286	25.2	26.5	22.0	21.7	16.3	15.7	19.1	14.4
23	22	18	67	22	32	26	32	22	6	2	0	1	228	252	216	366	25.9	26.1	26.0	22.3	16.6	17.8	19.1	20.0
24	22	36	50	40	36	22	32	22	6	7	0	3	300	232	286	288	25.5	28.2	25.6	25.1	18.6	15.6	19.8	17.0
0165																								
1	24	11	58	38	36	38	2	6	14	19	6	7	228	262	232	232	34.4	30.3	27.1	24.3	16.2	15.7	12.9	14.7
2	12	12	43	54	36	16	4	2	18	20	8	6	250	252	216	224	31.5	29.6	30.7	25.6	17.3	13.7	17.2	13.6
3	18	6	49	25	32	22	2	0	26	21	14	8	238	268	188	318	29.1	31.3	31.7	22.4	18.4	13.4	16.4	13.3
4	9	6	42	8	28	20	6	4	31	19	20	11	248	282	138	230	29.4	32.0	29.8	28.7	20.7	17.3	16.6	15.7
5	12	36	88	64	70	16	4	4	26	27	9	4	264	228	250	228	33.4	29.7	30.8	23.4	18.7	14.7	17.4	18.3
6	25	34	51	39	112	6	8	4	14	11	9	3	208	264	172	398	34.9	33.4	29.8	22.4	19.1	15.3	16.3	15.4
7	30	31	61	50	28	18	2	4	21	20	3	2	250	260	236	276	31.5	31.0	27.2	25.0	17.8	18.4	15.5	18.2
8	30	20	90	54	46	20	2	4	32	18	11	3	306	268	216	268	34.5	31.4	33.4	23.4	17.7	13.7	20.1	14.9
9	5	10	21	74	56	34	12	8	20	26	8	8	294	236	218	188	30.3	28.9	27.8	27.6	16.7	15.8	15.2	15.2
10	6	2	41	12	64	14	2	4	25	25	15	15	240	274	228	272	30.7	34.6	34.0	29.4	17.4	16.3	17.2	15.4
11	21	18	33	78	22	54	6	2	18	21	4	9	230	186	218	198	35.0	32.5	24.5	27.9	15.5	15.5	18.8	13.3
12	2	4	42	11	36	20	4	8	21	18	11	8	290	300	228	236	33.6	35.6	31.5	31.7	19.7	19.2	18.2	17.7
13	10	10	54	34	86	16	0	2	42	24	13	1	255	274	200	248	32.8	30.9	35.7	25.9	19.3	17.3	18.2	17.2
14	10	16	56	32	44	28	4	6	32	19	12	6	240	272	236	240	34.6	28.8	29.1	25.2	16.7	14.6	17.1	15.3
15	5	6	56	27	32	22	0	4	23	30	9	9	236	240	232	248	34.9	30.6	30.6	25.5	18.6	14.3	16.0	13.6
16	10	12	10	27	34	12	4	4	19	14	8	6	224	236	228	186	33.8	29.1	25.4	27.0	18.4	15.3	17.9	18.2
17	9	6	7	18	6	12	2	0	24	30	22	8	262	232	262	238	28.1	29.7	27.2	27.7	15.6	16.6	16.3	15.2
18	6	5	48	8	20	18	0	8	30	27	13	8	268	290	212	206	32.6	30.9	31.2	29.1	18.4	14.8	16.8	10.5
19	62	42	119	49	96	46	4	10	20	18	19	3	248	250	260	356	30.9	35.1	29.5	24.8	18.3	16.6	16.3	15.6
20	35	11	104	56	44	48	6	4	24	21	13	8	318	304	240	282	32.6	31.2	31.0	26.3	18.0	17.2	16.6	15.1
21	4	25	54	33	28	12	4	4	35	27	9	11	248	286	248	290	31.4	28.0	27.1	23.4	15.8	13.9	20.0	13.6
22	44	28	44	112	16	64	4	4	24	37	4	12	276	296	244	252	29.8	29.5	25.4	27.8	15.0	16.8	17.7	13.8
23	10	13	34	20	14	4	4	10	11	18	9	4	238	174	236	204	31.8	30.7	27.0	27.9	17.6	17.4	19.0	18.7
24	10	3	26	14	22	36	8	4	16	11	11	3	256	218	252	206	25.8	31.2	26.0	30.1	14.8	17.7	17.1	14.5

[a] Soil test data as reported by Alberta Soil and Feed Testing Laboratory except nitrate-nitrogen values 12-24" and 24-36" depths converted to lb/a/12 inches.

[b] Collection of soil test samples for 24-36" depth commenced in 1967 for sites 21, 23, 25.

[c] Site 2164: soil test values for exchangeable-K omitted, as a different extractant was used.

APPENDIX B. (continued)

SITE-YEAR & TMT. NO.	nitrate-N (lb/a)								available-P (lb/a)				exchangeable-K (lb/a)				soil moisture per cent (oven-dry basis)							
	0-6"		6-12"		12-24"		24-36"		0-6"		6-12"		0-6"		6-12"		0-6"		6-12"		12-24"		24-36"	
0166																								
1	15	16	5	8	4	8	6	8	13	9	3	6	248	256	504	268	28.4	32.8	19.1	23.3	18.6	16.2	19.5	17.5
2	20	20	4	13	4	12	2	10	15	23	12	6	308	294	264	268	35.3	29.6	29.2	24.9	20.0	17.7	20.3	16.7
3	13	12	6	44	4	4	4	6	20	22	3	6	286	230	384	400	32.1	29.5	24.9	21.4	19.7	16.2	21.2	15.7
4	17	10	8	4	2	4	4	2	23	14	6	3	274	296	306	436	32.0	32.1	27.2	19.8	17.8	17.0	19.2	21.3
5	22	18	18	11	50	16	24	12	14	8	6	3	250	268	260	354	34.4	31.5	29.2	21.3	19.5	16.2	21.8	20.8
6	15	18	9	8	18	8	20	22	13	14	10	1	220	308	454	342	30.7	31.9	21.8	23.1	17.7	16.1	21.1	20.4
7	25	26	17	10	12	10	12	8	26	21	7	3	276	300	308	416	30.9	31.4	25.1	20.9	20.0	20.2	19.6	21.3
8	28	15	18	17	28	8	14	8	28	17	9	3	274	200	352	318	32.5	32.4	25.1	22.4	19.0	15.7	20.9	18.2
9	27	25	17	9	10	6	10	4	17	21	6	4	322	274	304	230	33.7	31.7	29.4	26.5	18.8	16.9	19.1	15.7
10	20	10	10	4	6	2	2	2	25	19	9	4	232	276	260	276	34.9	31.3	30.0	23.5	22.2	18.8	21.4	18.5
11	20	33	9	12	10	14	30	14	14	16	11	4	236	238	412	216	32.1	30.2	20.2	28.0	17.9	16.3	21.4	15.8
12	19	14	9	8	24	22	20	26	0	12	6	12	276	276	250	318	35.4	31.0	31.9	25.4	20.6	17.5	21.3	18.5
13	20	17	10	6	4	4	6	2	28	35	1	4	216	248	354	308	33.6	32.2	23.8	23.5	16.7	16.5	21.4	21.1
14	16	16	13	10	10	8	10	8	17	13	1	3	272	272	296	328	34.4	29.4	26.8	21.6	17.4	17.4	19.3	16.2
15	25	20	17	8	12	8	6	8	20	11	3	4	276	224	286	366	31.4	31.3	27.0	20.1	17.8	16.2	22.1	18.8
16	25	10	8	5	10	6	18	10	8	7	1	1	312	286	342	460	30.9	30.5	22.8	20.6	18.7	17.4	19.3	22.1
17	14	19	4	6	0	8	0	6	17	39	10	3	280	220	318	286	36.5	30.1	27.5	24.7	20.8	19.0	21.1	20.0
18	19	25	7	6	0	4	2	4	10	38	6	8	318	260	232	238	33.8	30.6	29.5	25.4	18.4	15.3	21.9	14.1
19	20	24	15	13	58	54	50	58	6	11	1	3	286	256	374	366	33.6	32.9	24.9	20.5	19.6	17.2	22.0	19.3
20	18	22	25	23	58	86	32	50	9	14	3	6	276	330	330	290	34.7	31.8	25.6	26.0	17.9	18.0	21.4	20.1
21	20	28	9	12	8	10	12	34	25	25	1	7	262	230	468	386	29.7	30.9	21.3	20.3	17.6	15.2	21.5	17.0
22	33	12	23	22	26	56	12	18	28	20	8	6	304	280	294	288	31.8	28.6	24.8	25.6	19.5	18.1	22.0	16.2
23	25	15	8	5	12	6	10	6	13	9	3	9	300	264	318	348	32.9	29.1	25.3	25.6	18.7	20.4	21.7	20.9
24	11	18	7	6	6	8	4	10	11	7	11	0	318	252	372	408	32.7	32.1	25.3	21.4	20.5	17.9	19.5	17.7
0167																								
1	21	7	8	1	2	0	0	0	12	12	5	4	238	208	162	196	31.0	29.4	24.6	22.8	16.5	15.2	18.0	18.3
2	16	10	6	3	2	2	0	0	10	12	5	5	268	238	156	186	35.5	28.9	30.6	25.9	17.8	16.6	18.9	14.9
3	5	6	13	0	0	0	0	0	5	15	33	2	174	204	256	218	31.4	28.8	29.8	18.5	17.6	15.0	18.8	16.5
4	13	8	2	1	2	0	0	0	22	22	6	2	216	244	240	224	32.4	31.0	24.2	24.7	17.6	15.7	16.7	19.0
5	27	19	23	7	38	6	28	2	15	10	5	4	248	244	166	198	31.8	31.0	28.4	25.8	18.7	17.6	19.6	17.1
6	19	15	24	9	46	2	32	0	11	15	5	5	268	268	172	228	29.6	31.6	26.4	23.9	16.8	15.5	18.0	18.4
7	16	13	8	6	10	2	0	0	19	43	5	5	200	244	208	172	30.4	33.5	24.4	28.6	19.2	21.5	19.9	19.2
8	23	11	12	10	22	0	8	0	24	24	5	5	274	204	174	182	31.8	31.4	26.8	25.7	17.4	15.4	16.7	16.1
9	6	8	6	6	2	2	0	0	11	17	5	5	228	236	208	180	34.0	29.6	26.9	26.3	18.4	15.6	18.5	13.6
10	16	10	6	2	4	0	0	0	17	17	7	5	198	224	166	166	33.6	31.7	34.6	26.7	22.5	16.4	17.3	18.2
11	21	12	12	29	12	18	14	6	17	22	2	5	232	230	162	172	31.5	28.4	26.6	27.1	15.4	14.2	18.9	16.0
12	26	16	22	16	30	4	24	10	7	10	4	2	208	228	144	228	33.8	31.5	31.2	23.6	18.5	16.4	21.0	18.2
13	19	12	5	3	2	0	2	0	26	15	5	4	206	256	156	196	32.7	30.4	28.8	25.5	16.2	15.2	19.1	18.6
14	17	16	6	5	6	0	2	0	15	22	4	4	208	282	182	216	31.5	30.7	23.9	23.6	16.8	14.8	18.8	14.4
15	26	11	11	3	12	0	4	0	17	22	5	5	230	248	168	204	32.4	30.2	28.0	21.1	16.4	16.2	17.5	17.1
16	15	11	5	3	4	0	10	0	10	10	5	4	248	276	152	166	29.6	29.5	26.3	24.5	16.9	16.9	19.4	19.0
17	17	9	4	1	2	0	0	0	28	36	4	5	204	192	186	174	34.4	30.7	29.8	27.1	19.2	18.6	19.8	19.4
18	14	7	3	2	2	0	0	0	33	31	4	5	208	240	146	174	30.4	28.9	28.4	23.5	17.3	14.7	18.8	13.4
19	33	12	42	15	66	26	58	28	7	10	4	2	200	236	172	198	30.9	32.0	27.0	23.8	18.5	17.4	20.6	18.8
20	42	0	55	30	122	66	50	36	10	7	5	5	230	286	172	198	31.0	29.6	27.7	26.1	19.2	19.2	19.3	18.9
21	27	15	12	15	14	8	4	0	26	19	5	2	188	220	182	308	30.5	28.8	24.3	20.1	16.7	14.6	17.7	17.0
22	24	24	21	21	26	18	6	6	48	31	5	5	296	276	224	216	29.8	28.3	26.4	25.2	18.6	15.0	18.1	14.2
23	22	15	5	5	4	2	6	0	10	8	4	5	216	240	232	172	29.6	30.2	24.6	25.7	18.9	21.2	20.2	20.2
24	11	12	3	1	4	0	2	0	7	6	5	4	252	198	216	174	31.5	28.9	28.3	24.2	20.2	16.9	22.2	19.1

APPENDIX B. (continued)

SITE-YEAR & TMT. NO.	nitrate-N (lb/a)								available-P (lb/a)				exchangeable-K (lb/a)				soil moisture per cent (oven-dry basis)							
	0-6"		6-12"		12-24"		24-36"		0-6"		6-12"		0-6"		6-12"		0-6"		6-12"		12-24"		24-36"	
0365																								
1	3	3	2	0	4	0	2	2	6	6	6	1	386	248	306	380	12.5	12.3	15.1	15.8	12.9	13.1	12.0	11.7
2	3	5	0	1	10	2	0	2	6	8	4	0	252	200	240	304	12.5	11.5	14.1	16.1	14.6	12.8	12.9	12.2
3	2	4	1	2	4	2	4	4	6	12	0	3	198	206	404	306	12.8	11.8	18.2	14.8	15.5	14.1	13.2	12.4
4	3	2	3	1	6	4	10	2	3	8	0	6	312	230	440	356	15.2	13.9	17.2	18.2	12.7	13.3	12.9	10.5
5	5	2	4	1	10	4	10	4	3	15	0	3	308	308	368	392	14.2	13.4	17.7	16.2	13.6	13.1	11.9	12.8
6	3	3	1	1	10	4	16	4	14	8	6	9	172	354	318	476	11.1	15.3	14.9	16.5	13.9	12.8	13.6	11.1
7	3	2	2	2	4	0	8	2	9	3	0	0	262	204	386	440	14.0	12.3	17.0	17.7	14.9	14.8	13.7	13.2
8	3	2	0	2	2	2	4	4	9	0	3	0	294	330	400	408	13.5	15.7	14.9	21.8	12.9	15.2	12.3	12.2
9	2	2	2	1	2	2	2	2	6	9	3	0	336	300	354	352	12.8	14.6	16.1	14.3	13.3	13.0	12.8	11.0
10	5	4	10	2	6	2	8	4	6	6	0	0	268	186	384	354	14.3	10.7	19.0	16.3	13.4	14.0	12.0	11.7
11	2	4	1	1	2	2	4	2	6	0	0	0	304	230	330	478	9.1	13.9	13.7	16.3	13.6	13.2	12.1	13.1
12	3	1	4	1	8	2	22	2	0	0	0	2	324	348	436	400	14.8	15.1	17.9	17.0	14.2	13.5	12.7	12.8
13	5	3	4	2	8	2	8	2	13	9	3	0	198	174	428	330	12.7	12.2	17.7	17.4	15.3	14.4	13.2	12.7
14	5	6	3	4	8	2	8	4	0	4	1	3	324	324	432	386	14.2	11.8	17.3	15.0	13.5	14.1	11.7	12.7
15	3	2	13	1	4	0	6	2	11	5	3	0	384	204	440	360	11.0	12.0	14.5	15.5	13.9	15.8	12.3	14.2
16	9	2	2	0	2	0	0	0	6	9	10	3	200	280	404	372	12.1	13.6	15.4	16.1	13.5	14.3	12.0	13.4
17	2	2	2	2	10	4	8	4	9	4	1	4	224	342	368	348	13.3	13.2	15.4	17.5	16.5	14.0	14.2	12.5
18	2	11	1	3	4	2	2	2	5	3	3	4	276	322	404	436	12.8	15.3	14.3	17.3	12.2	14.3	11.4	12.0
19	15	5	6	9	8	6	10	2	6	4	4	0	290	240	428	224	12.7	12.6	15.3	13.5	14.3	14.9	12.6	13.8
20	4	2	3	3	4	4	2	2	6	8	0	0	230	236	342	372	14.4	10.9	15.8	15.4	14.0	15.8	13.5	13.8
21	2	2	4	4	4	4	0	4	3	5	1	1	204	182	416	392	12.0	12.9	17.4	18.0	14.4	13.3	13.1	10.8
22	5	2	3	1	8	2	6	4	3	9	0	2	304	182	388	244	14.0	11.9	16.7	14.4	12.6	14.1	12.2	13.3
23	1	2	2	1	0	0	4	2	0	4	0	0	300	260	438	424	13.6	13.1	17.9	17.0	13.8	15.3	12.3	13.4
24	2	3	1	1	2	4	4	0	6	10	0	0	180	188	404	448	12.3	11.5	14.7	14.5	13.4	13.2	12.4	12.4
0366																								
1	20	32	3	3	2	0	2	2	14	10	4	4	268	204	456	400	13.1	13.1	18.6	14.4	19.0	17.3	18.0	16.4
2	39	53	5	5	0	2	2	6	20	13	8	4	232	264	312	380	12.8	11.4	13.2	16.9	18.9	17.4	16.7	17.9
3	31	53	5	10	0	8	0	4	22	26	6	4	192	166	224	282	12.4	11.1	13.9	16.7	20.5	19.3	17.6	17.6
4	15	22	0	3	0	0	0	0	29	22	8	6	244	268	522	374	13.5	11.7	19.4	19.4	18.0	18.7	17.5	15.6
5	19	17	3	4	4	4	4	6	9	9	6	3	308	268	460	428	13.6	13.2	20.4	18.7	18.2	18.0	16.0	16.1
6	43	26	5	4	0	4	0	2	28	19	14	17	208	268	312	496	11.8	15.4	14.5	19.2	19.4	17.8	17.4	15.6
7	29	41	5	16	8	4	4	2	35	17	9	9	216	188	388	288	13.5	11.9	15.1	15.1	20.2	19.8	18.1	18.1
8	13	47	1	9	6	8	2	4	16	25	9	4	318	250	452	392	13.0	12.4	18.1	21.0	18.1	19.9	16.2	16.9
9	33	25	4	5	2	4	2	4	18	16	8	6	240	268	418	354	13.2	13.1	16.6	16.5	17.0	18.0	15.6	16.8
10	12	25	0	5	0	0	0	0	14	16	6	4	262	218	416	146	12.2	10.7	18.3	16.0	18.8	19.5	16.5	17.4
11	22	20	8	5	0	10	0	4	14	8	6	6	172	372	332	454	11.8	14.6	16.7	19.3	19.8	18.4	17.5	18.0
12	9	28	0	3	0	4	0	4	14	8	6	6	342	312	528	448	13.6	13.2	19.7	19.8	18.6	17.5	16.9	16.4
13	34	32	7	7	2	4	2	4	47	20	9	4	212	250	388	356	11.8	12.9	17.9	18.7	20.6	18.7	18.5	16.6
14	24	26	2	9	2	6	2	10	14	21	4	3	282	260	420	322	13.9	12.7	20.4	16.6	19.0	19.4	16.4	17.0
15	40	40	7	7	2	4	2	4	32	26	9	10	236	192	488	256	12.4	12.6	15.5	14.5	19.3	19.5	17.8	17.6
16	33	42	2	4	4	0	0	2	14	19	4	9	206	282	454	362	12.7	11.9	17.8	15.8	18.5	18.7	17.0	18.4
17	53	25	8	4	2	6	0	8	42	17	9	9	224	312	440	392	12.6	14.9	14.6	19.3	20.8	17.6	17.7	15.8
18	34	22	1	8	0	6	6	6	21	23	3	6	262	220	460	336	12.2	11.2	17.8	19.7	18.2	19.8	16.4	17.0
19	46	56	8	17	10	16	6	8	25	20	9	8	204	224	386	378	11.9	11.8	17.3	12.6	20.1	18.0	17.8	17.2
20	37	49	6	14	4	6	4	10	16	14	6	6	252	216	362	282	12.9	11.1	17.1	16.1	19.1	19.7	17.8	16.4
21	41	16	9	4	6	4	2	4	32	16	3	6	206	264	354	368	12.0	12.5	15.0	20.5	19.8	18.1	17.3	15.6
22	26	35	3	9	2	4	4	4	32	20	9	6	306	218	476	274	11.2	11.9	18.9	14.9	19.0	18.9	17.5	16.5
23	27	18	4	2	0	2	2	2	15	9	4	4	212	290	362	460	12.0	12.6	17.7	18.8	18.6	19.4	17.7	19.6
24	46	40	11	7	0	4	0	2	13	18	4	9	208	224	366	366	12.1	12.1	14.4	15.8	17.6	17.7	16.5	16.7
0367																								
1	23	27	9	11	2	16	2	8	12	15	2	2	280	206	306	296	11.4	11.2	18.8	16.7	15.8	17.8	16.9	16.6
2	37	30	31	22	6	2	2	2	17	12	2	2	212	212	262	236	11.1	11.3	14.6	15.0	17.8	17.0	17.2	16.9
3	23	26	15	9	2	2	2	2	50	19	2	5	196	186	200	180	11.1	10.6	15.8	16.1	18.8	19.2	16.0	16.9
4	9	15	2	6	2	4	2	2	19	19	2	2	250	228	262	228	11.1	11.7	18.3	18.7	16.5	18.0	16.8	15.8
5	23	42	9	28	2	8	2	8	7	7	2	5	252	238	316	308	10.9	12.2	18.4	19.0	15.6	16.7	14.1	16.8
6	25	38	37	25	14	10	6	6	19	10	5	2	224	252	256	294	12.2	11.6	16.8	17.4	19.5	16.8	17.8	14.8
7	16	36	33	11	12	4	2	2	59	22	5	5	218	198	288	280	13.9	11.9	16.5	18.3	18.5	18.1	16.8	17.0
8	40	46	25	13	2	6	0	2	33	55	0	2	232	238	340	280	10.2	10.9	16.6	19.9	15.2	17.2	14.2	17.0
9	15	18	12	10	2	2	2	4	12	15	2	5	238	240	250	264	12.1	11.9	16.3	17.6	15.8	16.3	16.0	15.4
10	9	40	1	7	2	2	2	2	7	19	2	2	268	218	294	312	13.2	10.2	18.5	19.5	16.5	17.8	16.4	17.2
11	46	35	39	11	8	4	8	2	15	7	2	2	186	248	244	274	10.7	12.8	16.0	17.9	17.6	16.3	16.4	17.3
12	42	51	18	14	4	2	4	4	10	5	2	5	274	276	328	286	12.3	11.7	18.8	18.0	16.5	16.6	16.2	16.7
13	24	29	23	19	10	4	8	4	26	26	5	2	236	208	368	294	11.7	10.9	20.0	18.6	20.3	19.0	17.4	17.0
14	13	52	1	25	0	8	0	8	17	19	5	2	276	220	324	324	13.4	10.2	16.8	16.0	15.6	16.7	14.6	16.7
15	20	39	16	31	6	8	2	2	15	41	5	2	294	232	238	268	12.6	11.4	17.5	14.2	19.5	19.2	17.7	17.9
16	27	26	10	17	2	16	0	2	10	15	1	5	218	262	312	268	9.4	10.7	15.8	16.0	16.8	18.8	16.1	18.3
17	18	11	12	1	2	2	2	2	24	24	5	5	212	272	244	272	12.5	13.2	15.0	17.0	18.9	16.2	16.9	15.8
18	6	12	1	4	0	4	0	6	15	17	2	1	224	224	306	276	10.6	12.7	18.4	21.0	16.0	18.6	14.8	16.4
19	51	71	38	61	4	20	6	12	10	12	2	5	268	200	318	206	11.2	10.1	18.2	13.6	18.6	18.8	16.8	16.8
20	39	46	51	16	26	22	12	14	10	15	2	5	238	188	296	186	12.2	10.8	17.3	15.6	18.4	18.8	17.0	16.8
21	30	39	13	15	2	6	2	6	15	22	1	2	188	230	318	290	11.1	11.9	19.0	17.8	17.7	16.5	17.2	15.3
22	63	51	18	33	16	18	6	8	59	29	2	0	250	238	324	276	10.7	11.1	18.0	15.5	17.0	18.0	16.5	16.5
23	29	30	21	14	2	4	2	6	12	12	2	4	230	248	290	248	11.8	10.6	18.7	17.9	19.2	18.9	17.5	19.2
24	47	36	19	10	2	6	2	2	8	12	1	4	212	228	322	252	10.4	12.1	16.7	17.0	17.1	16.7	15.8	17.2

APPENDIX B. (continued)

SITE-YEAR & TMT. NO.	nitrate-N (lb/a)								available-P (lb/a)				exchangeable-K (lb/a)				soil moisture per cent (oven-dry basis)							
	0-6"		6-12"		12-24"		24-36"		0-6"		6-12"		0-6"		6-12"		0-6"		6-12"		12-24"		24-36"	
0565																								
1	22	2	11	7	6	0	8	6	7	11	10	4	244	306	330	330	29.8	20.1	17.8	13.9	13.2	9.7	13.1	11.3
2	13	10	5	2	12	4	6	4	24	24	11	9	336	360	282	368	28.5	22.3	15.3	15.4	10.9	9.6	11.2	11.8
3	14	14	6	6	4	10	4	6	28	25	11	6	380	308	396	336	30.9	27.7	17.7	16.5	13.8	11.1	12.5	10.1
4	10	11	7	2	4	4	4	4	38	23	16	0	318	174	288	328	31.5	24.3	21.6	15.2	12.6	10.1	11.4	11.1
5	15	11	6	2	4	2	4	4	25	22	13	6	300	300	296	372	29.2	25.9	16.0	16.9	11.2	11.0	10.1	11.1
6	18	17	4	6	4	4	4	8	28	20	7	3	400	272	268	324	25.9	24.3	15.4	17.3	11.8	9.5	11.4	11.0
7	12	12	5	5	4	4	4	4	27	18	6	6	436	360	444	362	27.3	23.2	15.2	13.4	11.8	11.5	10.9	14.4
8	10	12	4	2	4	4	8	6	9	19	6	4	332	328	322	360	21.7	23.2	15.5	15.7	9.5	10.2	11.2	11.3
9	17	6	6	1	4	4	4	4	26	19	9	9	332	296	386	324	31.2	21.0	19.9	16.4	16.7	12.6	15.0	13.8
10	18	10	12	6	6	4	14	8	26	16	11	2	294	178	304	250	26.5	23.2	17.8	13.9	10.6	9.7	9.8	10.4
11	10	6	2	3	4	4	4	6	16	16	3	6	276	294	384	286	22.8	21.2	15.9	13.1	13.8	9.1	13.4	10.2
12	11	10	2	4	4	4	4	4	28	23	19	6	308	312	238	198	27.3	23.7	18.6	15.9	11.9	11.5	10.7	12.5
13	13	2	7	6	8	8	6	12	19	24	11	7	306	288	290	262	27.1	23.1	18.4	16.5	12.1	9.6	11.3	9.9
14	10	9	3	4	12	6	10	4	16	19	9	5	312	294	304	286	23.4	22.8	14.3	17.3	9.1	10.8	11.1	9.9
15	17	10	4	8	0	14	4	12	22	23	9	6	296	240	218	282	22.8	21.6	14.9	13.7	11.7	9.0	11.6	10.5
16	10	10	3	6	4	8	2	6	16	22	5	4	256	268	378	324	24.2	22.3	18.0	14.1	12.6	8.7	13.9	10.6
17	13	6	2	2	4	4	4	8	26	17	7	4	206	352	354	306	22.1	21.1	15.1	15.6	11.2	9.3	12.8	9.9
18	21	20	10	6	8	8	6	6	31	24	6	9	392	322	288	294	28.1	24.4	16.6	19.2	10.3	10.8	10.0	9.8
19	14	11	2	6	6	4	10	4	20	25	0	9	264	312	268	290	26.4	22.7	10.5	14.8	10.2	10.8	13.1	10.1
20	12	15	6	5	12	4	12	6	15	26	8	8	300	206	306	158	25.8	28.5	20.3	14.4	11.1	9.7	12.9	10.4
21	15	10	8	7	12	6	10	4	23	19	4	8	166	290	208	294	25.6	25.0	17.4	19.5	10.6	10.3	10.4	9.6
22	14	8	9	2	4	4	4	4	26	16	18	4	196	274	288	360	25.8	21.1	13.0	13.9	10.6	10.1	11.1	11.4
23	14	4	3	12	4	2	8	4	9	23	7	11	374	336	404	308	25.3	30.5	15.7	15.7	13.6	11.5	14.0	9.9
24	16	10	6	4	4	4	8	4	25	16	9	4	264	344	312	316	28.7	20.1	16.5	13.0	11.7	8.0	10.3	9.5
0566																								
1	16	6	5	1	8	2	4	0	26	17	7	9	336	354	386	342	27.9	19.8	18.0	17.3	13.4	14.4	13.9	12.9
2	14	5	4	1	6	2	8	4	11	11	5	0	352	352	360	408	26.6	21.4	16.1	15.9	11.2	11.7	11.7	13.4
3	16	8	3	3	8	0	10	2	32	19	4	3	340	294	460	308	29.6	25.9	20.6	15.7	17.6	12.3	13.7	11.6
4	8	10	3	2	6	4	8	4	18	21	6	9	328	366	404	432	29.0	21.3	18.4	17.7	14.6	12.4	12.0	13.6
5	25	10	7	1	4	2	4	4	16	14	3	13	416	328	328	360	26.9	21.9	18.4	15.8	11.9	12.5	10.5	13.1
6	9	11	14	3	2	4	2	10	21	9	4	3	360	328	400	366	26.2	22.0	17.6	15.6	12.6	10.5	12.5	13.0
7	19	8	2	2	0	4	4	8	26	28	3	4	352	344	478	368	24.4	22.9	18.7	14.7	14.8	12.8	15.0	14.8
8	10	12	5	2	14	2	4	8	13	22	9	6	380	386	354	420	19.1	21.6	16.3	17.1	10.9	12.8	14.5	13.1
9	17	9	8	4	10	2	12	0	27	16	3	6	366	340	304	418	31.8	21.9	22.5	19.1	20.6	14.4	16.8	15.0
10	14	9	2	1	4	8	0	12	20	21	5	5	322	316	400	344	26.4	21.6	17.5	16.0	13.8	13.0	11.4	11.7
11	17	5	5	2	6	2	4	4	13	18	0	9	342	322	416	352	22.6	21.7	18.7	15.1	14.5	10.1	15.4	12.3
12	11	13	3	3	10	2	8	8	12	14	10	4	342	352	360	404	24.1	20.6	15.7	15.7	12.4	12.6	13.8	14.2
13	11	18	4	3	6	4	12	2	17	20	7	0	340	300	332	282	25.1	24.2	18.6	18.2	12.2	12.7	10.8	11.6
14	13	14	5	2	4	0	8	2	21	17	8	9	340	316	342	348	22.3	23.5	18.1	17.2	12.8	11.7	14.0	11.8
15	10	11	0	4	0	6	0	10	32	14	7	7	476	294	416	330	21.6	24.1	17.0	15.4	12.7	10.9	13.2	10.5
16	10	8	3	2	0	0	8	2	10	11	7	13	322	330	396	344	25.9	21.2	19.0	16.7	15.7	14.4	17.6	13.6
17	15	7	1	2	0	6	4	2	92	23	3	6	392	356	440	324	24.3	21.9	17.8	17.2	14.0	13.7	13.8	13.5
18	17	10	2	1	4	4	10	2	23	39	5	8	342	344	348	354	25.0	24.2	16.9	18.0	12.2	12.7	13.5	12.5
19	10	16	2	6	2	2	10	6	15	14	3	9	360	316	438	316	23.1	22.5	16.6	16.1	12.3	12.2	12.6	11.9
20	15	17	3	7	2	10	2	8	9	12	4	8	372	318	374	280	24.2	25.0	15.9	20.7	11.0	11.9	13.6	13.2
21	20	18	5	5	2	0	0	0	28	20	9	5	354	322	316	296	26.9	23.8	19.6	17.4	12.8	11.9	11.8	10.4
22	41	14	11	3	0	2	0	2	33	20	8	2	396	332	282	342	26.7	21.0	17.2	14.6	13.5	10.3	14.2	11.6
23	11	12	0	2	2	6	6	2	18	19	7	5	324	312	306	360	26.1	24.1	17.2	16.0	16.9	12.9	15.7	12.5
24	25	8	7	1	14	2	6	4	15	15	7	4	404	362	352	348	25.7	19.5	17.7	16.9	12.5	13.6	11.8	13.2
0567																								
1	27	15	5	2	4	4	2	2	24	15	10	4	348	328	322	274	30.3	18.7	18.7	17.5	16.1	16.3	13.2	15.3
2	24	24	4	5	4	6	4	4	24	19	7	7	444	378	288	362	30.7	23.8	21.1	17.6	16.3	14.8	13.0	11.9
3	20	20	7	5	4	8	2	8	48	26	10	7	384	282	372	312	30.6	22.2	22.4	16.5	19.8	14.8	14.6	11.0
4	30	19	6	3	6	4	2	4	57	50	10	5	362	372	288	348	30.3	21.9	20.0	18.0	16.4	17.0	12.2	15.7
5	27	28	8	11	8	8	0	8	24	26	10	7	360	372	274	272	31.6	24.2	19.9	18.8	16.3	15.1	11.4	12.7
6	23	19	25	3	8	4	0	8	26	19	10	4	388	342	316	316	29.7	20.6	20.2	18.3	17.5	16.6	12.4	13.7
7	25	16	6	7	6	8	4	4	36	22	5	5	362	360	380	288	24.1	24.0	18.3	19.1	18.1	16.5	14.8	15.8
8	19	20	7	4	12	8	4	2	53	48	7	4	324	312	262	324	20.5	21.7	17.0	18.4	14.9	15.9	11.6	11.9
9	20	15	11	6	4	6	4	8	36	29	12	7	400	328	316	290	31.6	22.2	24.9	18.5	20.7	18.5	16.1	14.3
10	25	25	6	4	4	6	4	8	33	22	15	5	332	322	262	262	27.1	21.0	18.8	18.9	18.4	16.7	14.2	14.1
11	19	19	5	3	4	8	8	4	19	26	5	5	330	316	276	290	25.6	20.9	12.2	17.9	17.4	16.2	12.1	11.9
12	22	14	7	4	8	4	6	2	19	17	5	5	362	300	250	290	26.2	21.4	19.3	18.2	16.5	16.6	12.1	12.0
13	19	23	7	7	10	10	8	10	29	36	7	7	372	288	280	240	18.8	25.0	20.3	17.6	17.6	15.2	17.1	11.0
14	16	19	3	4	4	8	4	2	22	15	7	2	342	238	248	272	22.0	23.0	16.7	18.0	14.8	16.0	12.4	12.7
15	15	24	6	5	8	8	4	8	29	22	7	5	336	294	342	264	25.2	24.7	19.7	17.7	16.8	14.8	12.6	10.5
16	19	23	3	3	2	8	2	8	15	19	5	5	340	340	296	282	23.2	21.6	19.5	18.1	18.6	15.7	16.0	14.4
17	24	15	4	2	4	2	6	2	83	50	6	7	384	304	356	262	25.5	20.1	19.7	17.1	19.9	16.5	17.4	14.1
18	11	13	1	6	0	4	0	4	41	17	7	19	400	282	288	236	31.2	24.6	19.4	19.4	16.5	17.5	13.6	14.6
19	25	28	16	13	30	22	8	10	19	15	5	6	288	280	312	228	25.0	22.0	18.8	16.2	15.7	14.9	11.7	13.1
20	19	25	22	19	26	40	8	8	17	19	7	10	328	304	256	240	22.3	23.8	19.0	16.8	16.3	16.4	14.1	12.7
21	22	25	5	11	8	12	4	4	22	43	6	10	306	316	296	238	24.6	24.7	19.2	19.2	16.8	16.2	14.3	11.4
22	26	23	7	9	8	18	4	12	69	50	10	5	448	354	268	312	27.1	22.6	16.9	17.8	16.5	16.6	14.4	13.6
23	19	31	4	5	2	8	0	6	22	22	7	10	318	318	318	312	27.4	25.4	20.4	17.0	18.8	16.8	16.3	12.0
24	29	12	4	2	2	4	2	2	19	17	7	7	348	324	264	268	29.7	19.9	21.4	16.2	16.5	16.0	11.5	14.8

APPENDIX B. (continued)

SITE-YEAR & TMT. NO.	nitrate-N (lb/a)				available-P (lb/a)		exchangeable-K (lb/a)		soil moisture per cent (oven-dry basis)			
	0-6"	6-12"	12-24"	24-36"	0-6"	6-12"	0-6"	6-12"	0-6"	6-12"	12-24"	24-36"
2164												
1	20 18	43 29	158 54		44 42	9 6			25.8 23.2	17.0 24.5	17.9 15.8	20.6 15.8
2	19 18	27 31	80 90		42 35	8 3			25.6 22.9	25.2 24.5	13.2 17.8	23.1 18.1
3	20 16	50 20	58 40		46 29	8 6			26.3 24.5	27.5 25.1	13.2 11.4	18.1 12.8
4	19 18	40 38	94 112		55 61	9 19			24.8 21.8	26.9 27.9	14.9 19.7	17.7 20.8
5	22 16	52 25	112 90		46 42	11 4			25.0 23.2	24.8 22.9	15.7 9.8	25.4 17.8
6	31 36	56 27	90 90		44 35	10 1			25.8 25.1	26.1 25.2	14.0 16.6	23.8 17.3
7	22 36	29 45	104 112		12 41	36 3			26.2 22.4	26.8 24.6	16.4 18.5	21.4 16.0
8	16 27	40 31	94 58		35 44	0 11			27.2 25.2	28.9 26.1	17.7 14.8	21.5 19.1
9	20 18	45 40	126 104		39 60	11 11			27.5 24.4	29.2 24.8	18.3 15.1	18.6 21.5
10	31 22	52 47	112 100		53 35	9 6			25.5 26.3	24.9 26.7	15.1 14.6	16.5 13.6
11	18 43	63 50	134 80		35 47	8 6			26.9 25.9	27.8 28.0	17.9 16.5	18.2 19.7
12	18 18	47 40	54 90		50 58	9 14			25.3 27.2	27.2 25.5	19.0 12.9	23.2 17.4
13	22 16	45 18	112 126		55 41	13 9			24.2 24.5	27.4 24.4	17.2 13.9	25.4 18.8
14	20 20	19 27	108 54		3 29	35 0			25.4 25.6	28.4 25.3	21.7 15.8	15.7 22.4
15	19 16	50 38	158 134		51 30	14 3			30.9 22.6	28.9 23.8	18.5 18.9	21.4 12.8
16	36 18	63 22	94 80		51 37	9 9			25.8 25.1	28.7 25.4	17.5 13.0	22.0 21.0
17	18 22	47 54	108 108		47 47	7 4			25.0 24.7	23.1 27.0	14.5 18.2	22.2 21.2
18	22 18	52 45	134 90		22 54	13 10			25.6 24.3	26.1 25.4	19.0 14.1	21.3 20.9
19	47 18	54 50	86 94		23 37	11 4			26.2 25.0	27.4 26.7	18.2 13.1	22.6 18.5
20	27 18	47 29	134 94		35 21	3 0			27.5 22.8	27.8 25.3	18.9 19.7	21.2 12.7
21	20 20	67 22	104 36		52 48	11 8			22.3 24.5	27.2 23.3	17.2 9.7	21.9 19.0
22	22 31	50 50	134 126		58 39	12 4			25.9 23.1	26.6 22.2	17.2 14.3	29.8 21.8
23	29 18	52 18	112 44		38 48	11 12			25.7 25.3	26.0 23.6	15.8 11.4	20.4 21.6
24	18 38	67 47	158 94		52 38	22 6			24.6 23.2	27.2 23.8	14.2 19.4	17.9 23.3
2165												
1	15 8	46 12	174 56		56 35	21 9	800 588	308 220	36.2 33.7	33.9 32.0	24.3 33.2	20.2 20.0
2	28 15	22 16	84 60		41 41	7 7	558 636	212 290	39.9 31.1	33.4 30.6	20.4 25.0	18.4 20.0
3	10 7	14 9	70 34		41 46	6 16	418 476	180 272	38.3 35.0	31.0 30.6	20.7 16.2	20.8 19.9
4	9 12	25 22	158 126		45 82	6 11	428 516	162 168	38.6 36.6	32.5 42.7	20.3 24.6	19.6 17.7
5	11 9	22 21	108 58		47 42	22 6	688 500	300 230	36.6 35.7	34.6 30.9	25.3 16.3	19.6 16.2
6	19 21	27 29	110 90		45 69	4 11	600 684	250 272	41.2 36.5	34.1 31.0	21.8 25.0	19.3 20.0
7	14 11	15 33	154 106		61 44	7 3	562 472	262 220	40.4 34.4	35.7 29.8	22.8 24.6	17.6 21.6
8	69 17	18 36	56 44		70 95	3 3	498 504	218 232	39.8 36.3	34.5 31.8	22.4 19.8	17.6 16.6
9	14 12	23 27	80 100		57 78	12 13	632 600	268 178	38.7 38.6	33.2 33.4	19.1 24.4	20.8 18.7
10	5 15	18 16	118 32		49 57	14 3	380 600	204 238	38.8 36.2	32.1 33.9	22.6 24.3	21.7 20.2
11	10 13	15 20	32 90		31 57	0 20	476 756	228 324	40.0 37.3	35.8 36.4	22.8 25.0	18.9 20.0
12	13 8	14 15	50 82		51 54	28 6	956 424	452 162	37.1 36.8	36.3 42.1	25.0 20.0	20.0 19.1
13	20 6	11 18	100 64		61 54	30 11	1132 572	440 262	37.6 28.1	35.3 33.0	25.0 20.1	20.0 14.9
14	10 6	20 11	60 28		33 21	6 0	522 368	268 218	40.3 38.6	34.5 36.1	20.8 21.5	21.2 20.9
15	9 10	26 23	194 74		61 28	14 3	512 368	186 224	38.7 33.8	38.1 29.9	27.2 21.5	17.8 15.6
16	15 15	28 21	40 52		84 38	26 6	960 704	368 232	37.6 37.0	37.7 34.4	25.0 18.4	20.0 16.7
17	16 11	22 18	52 78		73 66	7 14	480 556	172 188	38.4 37.5	15.2 37.7	20.8 25.6	15.3 19.9
18	15 11	21 20	60 82		57 98	17 28	836 584	384 304	37.6 39.0	37.1 30.7	25.0 20.9	20.0 15.9
19	16 14	31 36	90 102		59 35	23 4	608 536	612 244	36.6 35.2	38.8 33.8	25.0 23.2	20.0 16.6
20	18 10	38 16	114 44		28 20	2 6	552 524	250 200	39.5 33.9	33.3 33.6	23.3 23.3	17.4 20.0
21	37 11	52 26	110 94		5 37	7 7	204 388	300 188	39.2 35.3	36.8 22.6	25.0 16.3	20.0 15.2
22	22 7	63 26	210 130		66 77	13 18	556 792	212 352	40.7 35.0	37.0 33.4	26.3 25.0	19.9 20.0
23	16 14	19 16	56 56		32 39	8 9	484 428	230 180	40.6 35.5	32.8 28.1	21.2 17.3	17.1 19.8
24	12 13	18 18	102 40		47 41	8 6	374 572	146 252	37.7 33.1	33.9 28.7	20.7 25.7	19.8 15.2

APPENDIX B. (continued)

SITE-YEAR & TMT. NO.	nitrate-N (lb/a)								available-P (lb/a)				exchangeable-K (lb/a)				soil moisture per cent (oven-dry basis)							
	0-6"		6-12"		12-24"		24-36"		0-6"		6-12"		0-6"		6-12"		0-6"		6-12"		12-24"		24-36"	
2166																								
1	29	23	26	28	16	18			40	36	8	9	672	460	238	224	25.4	32.6	27.1	28.1	21.6	19.4	17.4	15.4
2	16	34	22	13	16	58			36	38	6	8	524	558	182	224	31.3	29.0	27.8	24.0	18.7	19.5	17.7	23.2
3	26	23	18	17	24	12			39	73	8	16	400	472	308	218	28.6	29.7	26.6	24.0	13.4	10.7	16.1	16.3
4	14	12	24	17	30	56			67	85	14	11	504	522	204	178	31.3	30.3	29.6	26.6	18.3	19.9	20.6	22.8
5	27	27	41	39	24	40			53	69	11	16	576	552	300	220	25.5	33.0	27.8	29.3	13.9	21.2	16.3	17.2
6	29	25	43	41	64	32			58	47	10	9	556	600	238	248	32.2	30.6	26.0	24.3	13.6	13.7	19.8	16.8
7	25	29	45	34	36	46			82	73	27	3	600	528	272	216	29.3	31.7	29.9	28.8	13.8	15.4	17.6	17.4
8	18	30	30	29	26	50			48	92	4	9	464	588	230	228	31.9	32.4	28.1	26.8	17.1	17.8	16.9	16.2
9	26	11	30	35	36	40			77	76	8	10	500	552	228	162	28.5	27.2	26.3	30.4	14.2	19.9	14.8	17.1
10	10	28	23	13	18	12			91	45	23	7	912	468	212	196	27.4	30.2	32.3	28.4	14.4	14.7	17.1	19.2
11	15	17	35	49	50	60			47	87	8	7	556	424	260	198	28.4	29.0	30.0	30.3	16.8	17.1	17.9	19.6
12	17	24	11	35	18	64			35	60	3	28	584	712	294	180	29.3	28.4	27.3	26.3	23.0	13.0	12.9	18.2
13	29	27	34	12	50	38			77	127	14	17	656	558	264	262	30.3	32.3	30.1	29.9	21.6	17.7	18.8	18.8
14	26	25	40	24	18	14			66	70	8	10	562	380	276	264	32.2	29.3	30.5	24.6	20.7	13.3	15.6	10.9
15	11	29	24	33	62	46			114	54	19	2	408	600	192	218	31.0	26.4	30.2	24.0	19.4	21.4	18.3	13.7
16	30	25	25	16	16	18			44	32	7	9	594	684	186	264	30.5	30.0	28.5	28.9	17.9	15.5	19.7	17.8
17	19	37	11	23	20	24			109	71	7	4	480	424	188	200	29.1	28.6	31.6	26.1	14.5	15.9	16.5	18.0
18	27	15	19	15	16	18			98	98	14	11	616	600	224	196	28.9	30.9	26.2	26.8	14.0	16.0	17.3	19.1
19	19	16	52	39	98	36			44	29	9	4	472	460	186	206	32.1	33.2	26.3	29.3	17.0	16.9	20.5	16.0
20	35	25	43	26	114	52			30	8	6	9	454	262	218	308	29.9	18.1	29.2	24.0	21.6	19.3	16.8	13.4
21	33	25	52	35	114	60			96	73	6	16	524	444	192	208	31.6	27.9	28.8	23.0	13.4	10.7	20.2	14.7
22	22	17	51	31	142	64			73	63	9	9	444	478	204	212	28.6	30.4	24.8	30.6	10.3	19.6	20.4	20.4
23	30	35	25	29	14	24			32	58	9	17	562	600	224	182	29.9	32.3	29.7	27.7	20.9	16.2	16.2	20.7
24	16	22	17	33	48	26			56	14	19	15	562	356	172	342	29.3	31.4	30.9	38.8	19.4	21.2	13.6	18.7
2167																								
1	10	7	21	19	18	0	70	6	50	38	10	5	784	520	256	204	32.7	28.5	33.0	24.5	15.0	8.8	17.4	18.2
2	9	11	16	15	22	18	22	8	64	55	10	7	548	540	204	220	30.8	28.7	29.9	25.0	15.1	16.8	17.5	17.5
3	6	7	40	5	46	0	20	0	90	57	7	10	492	460	198	240	30.9	29.2	32.1	24.5	12.9	9.8	17.4	8.4
4	8	18	33	26	76	58	98	72	78	120	15	31	500	644	198	238	31.4	28.8	29.5	27.6	15.5	17.7	15.9	17.1
5	6	6	57	15	46	0	96	14	50	50	7	15	566	522	260	232	31.2	29.4	24.3	24.0	14.1	11.4	14.8	15.6
6	4	7	38	37	90	34	6	26	55	45	10	15	484	464	240	238	32.2	30.8	30.5	25.8	14.5	25.3	17.8	19.4
7	4	9	7	0	54	2	102	34	83	76	24	10	476	576	230	224	32.4	28.8	28.9	27.4	20.0	22.9	14.4	13.8
8	5	10	6	7	46	34	44	48	76	116	10	48	556	664	228	360	34.9	31.4	32.1	30.8	19.7	26.6	19.0	16.9
9	8	9	9	13	22	10	52	6	64	114	7	15	478	504	236	182	34.1	28.8	31.8	24.2	19.4	14.1	13.1	20.1
10	6	13	12	9	6	2	12	2	93	41	19	5	732	440	180	296	29.6	31.0	29.3	21.5	17.7	14.7	15.3	19.7
11	8	8	15	23	74	68	126	44	64	114	7	19	456	796	204	232	34.0	30.0	30.9	32.5	20.7	17.6	17.1	18.4
12	4	11	25	21	36	28	36	22	48	62	17	15	836	608	268	204	27.7	31.1	28.2	17.8	30.3	12.8	19.3	22.1
13	6	7	7	17	32	26	68	30	121	107	12	10	1032	492	262	236	32.7	30.9	30.7	24.1	20.4	13.6	18.7	16.5
14	4	15	22	25	36	10	70	2	64	45	5	5	496	366	244	208	25.2	31.3	30.2	24.8	16.6	13.8	18.1	16.5
15	5	3	15	20	92	26	112	20	114	116	17	10	472	712	178	232	31.1	28.9	30.7	27.9	20.4	23.9	17.8	14.0
16	7	8	9	19	38	8	14	6	43	31	19	12	696	548	212	250	28.9	29.9	30.3	26.5	20.1	13.7	20.7	15.5
17	7	11	4	9	20	20	12	4	93	121	17	15	424	500	166	196	33.3	29.3	30.6	30.5	13.7	16.3	12.5	17.8
18	7	8	18	11	30	12	34	2	114	109	15	7	784	566	182	156	31.2	30.0	27.8	28.1	13.6	14.1	18.1	17.8
19	7	39	65	34	122	66	90	78	41	17	15	17	498	344	196	316	30.2	31.0	31.2	29.6	20.4	16.8	31.2	15.2
20	7	5	26	52	136	50	88	66	36	17	7	7	600	420	206	198	35.8	29.2	31.1	26.4	20.9	21.7	19.7	19.2
21	14	1	65	34	122	8	84	78	86	109	10	12	412	416	198	180	31.7	29.3	28.2	24.8	17.3	12.3	19.6	12.1
22	28	11	80	20	150	34	144	38	144	112	12	10	496	600	188	220	28.4	29.2	26.3	26.6	15.1	16.3	15.8	13.9
23	9	10	12	10	30	66	60	72	33	144	15	15	600	456	228	200	33.6	29.7	31.1	24.3	17.5	11.6	18.6	13.8
24	12	12	17	28	22	18	70	24	48	33	17	5	420	592	152	235	30.7	29.2	23.8	27.1	16.5	20.1	20.8	19.8

APPENDIX B. (continued)

SITE-YEAR & TMT. NO.	nitrate-N (lb/a)								available-P (lb/a)				exchangeable-K (lb/a)				soil moisture per cent (oven-dry basis)							
	0-6"		6-12"		12-24"		24-36"		0-6"		6-12"		0-6"		6-12"		0-6"		6-12"		12-24"		24-36"	
2365																								
1	3	1	1	1	2	2			54	49	16	14	306	304	300	400	23.1	21.8	17.0	18.1	17.6	10.3	12.6	11.6
2	2	2	2	1	4	2			51	42	21	11	208	260	276	332	20.4	23.5	15.7	15.2	17.3	12.8	13.6	13.6
3	5	1	2	4	8	2			47	54	19	20	316	412	416	294	21.4	20.6	19.5	14.9	15.0	16.1	9.9	12.7
4	3	10	3	2	6	4			38	63	11	16	380	286	360	304	21.7	21.3	19.2	18.7	18.6	17.4	11.0	15.0
5	5	2	0	2	2	2			56	58	25	13	216	328	344	374	21.1	20.7	17.9	16.7	17.6	15.7	12.0	19.9
6	2	5	2	1	4	4			55	59	23	16	264	294	342	366	22.9	23.2	18.2	15.2	17.3	12.8	12.9	13.6
7	6	1	3	1	8	0			58	51	35	9	340	348	356	380	21.0	23.4	16.2	18.2	14.8	16.2	13.6	11.5
8	3	2	2	1	4	4			55	47	11	6	282	374	344	354	21.3	20.2	14.6	18.5	17.1	16.5	12.3	14.5
9	3	2	2	2	6	4			51	72	13	22	288	304	384	322	19.1	21.6	17.4	16.1	16.8	17.8	10.6	15.8
10	3	0	4	2	6	4			58	51	16	11	236	260	332	340	22.4	23.6	19.0	18.1	17.9	16.8	12.3	11.9
11	4	3	1	1	2	2			54	58	9	15	260	280	316	408	22.1	18.9	15.0	18.7	17.5	18.2	13.6	12.0
12	4	1	3	1	4	2			65	50	16	12	256	368	304	342	22.0	20.9	15.0	18.4	16.3	17.5	13.1	16.3
13	5	0	2	1	4	2			52	60	9	15	252	286	296	374	19.3	21.8	16.9	17.8	17.2	16.9	12.3	11.4
14	4	4	1	1	2	0			59	55	30	14	288	282	352	342	22.2	20.8	16.1	17.2	17.9	17.3	11.7	12.9
15	2	3	2	1	4	2			46	55	9	17	496	288	278	352	22.7	22.8	19.4	18.6	17.6	17.8	13.8	13.6
16	5	3	3	1	4	2			54	52	13	13	280	276	340	392	21.4	27.6	18.3	18.0	16.5	18.6	11.6	15.5
17	2	2	3	2	6	6			55	55	14	16	204	280	330	288	23.6	21.8	17.8	17.6	17.2	17.2	13.4	13.7
18	2	3	3	3	4	0			45	60	3	20	328	248	238	330	22.1	21.1	18.3	17.3	17.0	17.7	12.9	15.3
19	6	4	0	2	10	2			55	46	20	8	260	322	354	396	22.2	22.7	18.3	22.0	18.0	17.9	11.8	11.9
20	5	13	1	0	0	6			56	53	12	16	262	312	286	464	22.5	22.7	18.2	20.4	18.1	16.8	13.1	11.6
21	3	1	2	1	4	2			49	47	22	19	392	276	296	348	23.1	20.3	15.4	17.8	16.3	18.0	14.7	17.2
22	3	2	4	1	8	2			48	47	13	6	378	300	432	348	19.4	22.4	21.2	20.0	18.0	17.5	15.9	12.8
23	4	0	2	1	6	2			56	55	22	23	294	296	256	300	21.1	21.2	16.1	17.3	17.4	16.6	14.5	12.3
24	2	1	4	1	6	2			61	54	30	8	296	236	308	356	22.3	21.6	17.6	18.6	17.5	16.2	13.0	13.1
2366																								
1	18	12	5	6	6	2			22	59	9	13	280	276	464	404	21.0	15.4	18.0	15.2	14.1	15.3	13.9	15.3
2	25	19	6	3	8	2			59	47	19	6	296	268	306	448	18.0	13.2	15.5	15.9	17.2	14.3	14.9	15.1
3	16	14	2	4	4	12			46	49	6	11	306	240	440	354	15.9	15.9	16.8	15.8	16.8	11.8	16.0	12.2
4	17	29	4	3	4	8			47	70	11	13	354	352	362	356	16.1	16.6	13.8	15.3	17.1	14.8	13.7	15.6
5	17	20	5	7	8	8			42	54	12	11	250	272	384	342	17.5	16.8	11.9	15.8	14.4	16.3	13.7	15.3
6	27	17	6	6	6	6			51	52	11	9	290	294	398	472	18.4	16.7	16.9	18.5	12.0	18.1	13.2	15.8
7	19	9	5	4	8	2			72	70	16	4	328	374	496	552	15.9	15.5	15.8	18.4	11.8	12.5	12.2	15.8
8	19	9	8	3	6	12			59	38	8	1	264	352	392	468	16.5	14.0	16.0	17.5	13.8	15.4	13.8	14.0
9	24	13	3	5	6	4			63	49	17	7	336	244	420	374	15.2	18.9	15.2	15.0	13.2	13.0	15.1	14.7
10	35	13	6	4	10	6			66	58	13	9	360	280	412	400	19.1	15.1	15.1	17.6	15.0	16.4	15.6	16.5
11	20	17	8	9	8	20			67	120	9	3	262	352	396	412	19.2	17.0	15.1	16.7	15.0	14.7	13.6	15.6
12	19	10	8	3	10	4			46	38	14	10	294	296	240	356	16.5	17.0	11.8	17.0	11.2	17.6	13.4	13.9
13	15	19	5	2	6	10			35	98	14	16	250	280	240	356	17.1	14.9	15.4	13.4	13.6	13.3	12.9	14.3
14	15	23	6	4	10	6			81	58	20	6	340	264	456	398	12.5	16.2	16.3	15.7	16.6	12.6	14.5	13.2
15	13	14	5	5	8	4			67	90	6	6	360	318	468	464	16.4	14.5	17.0	16.7	16.3	13.5	13.4	12.4
16	13	12	4	5	6	6			51	57	23	4	418	256	294	416	16.6	15.5	13.4	14.3	15.4	14.0	18.1	13.7
17	14	11	5	3	4	6			59	82	17	6	290	220	374	356	18.0	17.4	17.5	15.5	15.9	15.6	14.6	14.9
18	13	17	4	6	6	8			63	61	4	11	276	238	418	378	15.0	17.1	16.5	14.9	10.7	16.3	14.3	15.1
19	9	26	7	8	12	4			51	54	7	17	240	380	436	360	15.1	14.4	17.6	14.9	18.4	15.9	19.3	16.0
20	28	26	6	12	8	18			47	41	12	3	324	322	500	454	17.0	14.3	16.9	16.6	15.5	11.3	14.1	10.8
21	12	11	5	3	6	8			53	63	17	17	304	262	368	300	17.8	16.4	15.9	16.1	17.5	18.1	14.8	17.6
22	14	29	4	5	4	14			53	47	4	9	380	290	444	384	15.9	16.1	18.9	16.3	14.9	17.2	12.5	15.8
23	20	6	4	3	4	4			53	35	20	14	256	324	280	384	15.9	15.8	14.2	17.8	13.6	18.4	13.2	15.3
24	25	8	4	2	6	8			47	39	11	6	316	240	436	380	16.0	19.2	15.7	15.3	14.7	15.2	16.5	16.1
2367																								
1	19	14	14	14	8	12	4	4	78	69	12	19	324	318	378	288	16.6	18.9	18.9	13.5	17.5	19.9	16.1	18.1
2	14	7	4	6	6	6	2	0	69	72	12	15	306	276	308	362	19.0	13.6	17.6	18.0	18.0	17.8	13.9	14.1
3	8	2	7	12	14	16	4	14	86	86	22	24	316	330	252	238	17.2	20.4	12.3	15.5	17.8	15.6	15.0	16.2
4	7	11	3	10	2	8	4	6	78	90	12	15	378	290	352	316	16.3	16.6	16.5	17.0	17.6	16.3	12.8	17.2
5	10	1	8	15	12	20	6	10	50	57	15	12	230	274	294	332	15.6	19.6	16.6	16.1	17.4	18.2	14.3	17.2
6	18	8	11	2	14	12	6	6	86	52	29	10	356	372	250	368	18.6	15.7	16.0	15.9	16.4	16.8	14.2	17.4
7	11	7	11	4	10	10	4	10	83	95	22	10	300	340	374	420	16.9	15.0	16.9	16.5	17.7	17.9	13.7	17.8
8	18	2	18	2	14	8	6	4	86	88	7	7	308	330	360	362	18.1	15.7	15.0	18.2	16.2	18.8	16.1	15.0
9	17	22	14	18	16	14	6	6	83	78	17	12	340	264	330	236	15.8	22.6	14.5	16.1	15.6	17.6	13.0	17.0
10	15	8	15	8	10	8	6	2	93	86	17	12	318	328	294	308	19.3	16.9	16.0	16.2	17.0	16.8	14.7	16.5
11	18	5	9	7	22	10	4	8	95	90	24	17	322	340	228	282	19.1	16.7	14.5	15.8	16.9	18.8	13.5	15.9
12	13	8	13	10	14	6	4	2	57	36	17	7	274	288	250	344	15.9	15.2	14.1	18.3	13.2	18.1	13.3	14.7
13	12	8	8	7	12	2	6	2	120	105	12	15	290	294	296	322	17.4	16.3	16.0	16.2	17.1	17.1	16.7	14.1
14	11	9	7	9	10	4	6	0	90	105	24	10	282	264	332	340	16.7	14.5	18.7	16.9	18.1	17.3	13.9	15.4
15	10	12	7	5	2	2	8	6	97	100	12	15	438	356	318	336	18.4	13.5	10.1	18.7	17.2	18.1	16.1	15.7
16	8	12	7	14	6	10	4	0	59	62	19	15	272	374	288	312	17.0	17.9	17.0	16.2	17.7	17.9	14.7	17.1
17	14	15	12	15	4	8	4	4	93	100	19	12	248	288	348	244	15.8	20.4	18.3	13.2	17.9	17.6	14.1	18.3
18	13	11	8	11	6	10	4	4	102	120	10	17	282	286	290	262	16.1	17.0	10.5	15.1	17.1	17.1	15.0	17.5
19	11	8	9	5	20	24	14	14	55	55	12	10	268	354	342	384	16.5	14.4	17.4	14.5	17.5	18.4	14.7	17.5
20	7	15	15	9	32	24	18	16	55	55	19	7	342	360	272	432	17.2	14.8	15.5	20.8	16.2	19.6	14.8	17.4
21	12	14	12	11	12	14	10	14	76	93	17	17	268	276	332	296	17.4	18.2	17.3	14.4	16.7	17.6	14.1	16.9
22	8	12	12	12	14	22	6	10	88	86	7	15	408	296	362	276	15.8	15.6	18.6	16.4	17.2	17.1	20.8	15.6
23	12	8	11	7	4	6	2	0	67	55	22	22	260	260	238	340	19.5	16.6	13.7	16.0	17.7	16.9	19.1	16.5
24	7	8	8	6	8	2	4	0	52	57	15	15	328	288	336	312	18.4	13.2	16.7	17.3	17.7	18.5	17.2	17.6

APPENDIX B. (continued)

SITE-YEAR & TMT. NO.	nitrate-N (lb/a)								available-P (lb/a)				exchangeable-K (lb/a)				soil moisture per cent (oven-dry basis)							
	0-6"		6-12"		12-24"		24-36"		0-6"		6-12"		0-6"		6-12"		0-6"		6-12"		12-24"		24-36"	
2565																								
1	14	14	3	6	4	12			101	153	19	20	684	999	332	428	23.6	17.6	17.9	17.4	18.3	15.3	13.5	9.7
2	9	5	3	3	4	2			59	105	11	28	432	548	206	282	24.4	26.7	17.5	17.9	16.1	18.1	13.9	16.6
3	12	14	5	8	6	16			73	125	25	35	544	876	280	432	22.1	21.7	18.7	18.1	16.1	17.5	12.2	12.1
4	9	24	9	7	8	6			85	120	79	23	616	999	684	230	22.9	24.0	16.6	15.9	15.9	15.9	11.1	12.4
5	8	14	4	4	4	6			77	114	23	26	312	296	306	256	22.0	24.2	17.6	16.2	17.9	14.9	15.6	11.6
6	15	12	9	6	6	2			101	108	17	13	792	896	240	290	25.0	24.1	16.0	18.2	17.0	14.9	15.2	14.5
7	43	24	16	12	6	4			68	164	20	42	532	999	332	324	23.7	25.5	18.6	16.4	17.0	14.4	13.1	10.7
8	20	19	5	7	18	6			114	84	14	12	772	732	224	318	25.1	20.6	17.9	18.6	16.2	17.5	11.8	14.4
9	16	22	7	5	6	2			80	104	16	25	660	848	352	206	20.0	23.8	17.3	18.1	17.4	15.3	12.5	14.1
10	11	32	3	5	4	6			79	146	20	13	562	572	230	244	24.0	24.6	17.2	18.3	16.7	15.6	13.7	11.6
11	21	16	4	7	2	2			104	110	18	28	744	984	244	260	24.4	25.0	18.5	15.3	14.9	17.2	12.5	17.3
12	8	16	2	3	2	2			85	79	16	32	660	600	348	280	17.6	21.4	16.7	15.1	17.4	14.2	13.1	12.9
13	8	28	2	10	2	6			80	149	20	35	656	584	354	432	21.7	24.2	18.1	16.3	17.5	16.1	12.1	11.6
14	13	38	5	5	2	4			80	177	20	19	624	999	304	388	22.6	23.6	17.0	16.9	16.0	16.1	13.8	11.5
15	9	14	3	9	0	6			61	131	20	15	468	816	260	280	23.5	23.3	17.0	16.6	17.0	17.3	13.5	14.4
16	9	16	3	4	4	4			82	93	14	12	608	796	280	344	21.1	22.9	17.0	17.5	17.1	16.5	13.8	12.1
17	3	14	3	4	4	4			26	82	14	15	264	596	250	206	24.9	22.7	17.3	16.1	15.1	16.0	14.2	13.0
18	9	20	4	5	4	2			82	101	55	9	632	744	250	218	21.4	23.6	13.5	17.2	15.9	16.1	13.9	12.6
19	7	12	5	12	2	10			82	130	33	16	600	536	268	352	21.2	25.0	15.8	16.8	18.1	17.0	14.8	14.8
20	20	17	5	1	2	2			104	163	13	9	748	999	424	544	25.5	24.5	16.5	17.7	19.0	15.9	13.3	16.4
21	9	14	5	1	4	2			85	90	9	39	612	720	280	272	22.4	25.5	16.3	15.8	18.6	15.7	12.4	12.5
22	5	9	0	7	0	6			71	124	26	26	456	776	206	244	21.2	25.0	16.9	15.3	16.2	17.2	10.5	17.3
23	20	9	7	2	4	0			85	89	20	28	748	584	296	238	25.7	24.5	18.4	15.6	17.2	14.0	12.6	13.6
24	14	3	3	8	4	2			90	108	28	34	584	772	208	318	22.4	25.2	15.2	18.2	16.6	16.0	14.9	13.7
2566																								
1	10	18	3	4	4	4			55	178	5	33	576	960	440	572	15.3	16.8	14.1	14.1	14.9	12.2	12.4	9.2
2	12	7	2	2	0	2			63	176	9	17	484	576	252	356	14.0	17.9	10.1	12.2	12.7	11.2	13.4	13.3
3	9	15	1	5	0	2			63	139	9	26	408	908	360	400	14.0	14.5	15.5	13.5	10.6	12.6	8.9	10.6
4	6	10	4	3	2	2			76	99	11	21	540	684	340	282	16.1	15.1	13.2	10.4	14.1	11.0	13.1	13.4
5	18	11	7	5	2	8			84	117	9	25	592	572	362	282	16.3	15.9	13.9	13.9	10.8	15.1	11.5	12.2
6	25	24	4	8	2	2			73	92	6	20	516	836	276	304	15.4	15.9	13.3	11.6	13.3	8.4	14.3	11.6
7	14	18	6	3	2	2			80	149	6	25	576	880	354	444	16.4	17.1	14.4	13.3	11.6	12.2	13.9	12.3
8	18	27	16	8	2	0			63	89	4	14	600	712	330	418	14.1	17.2	13.1	20.4	12.0	12.4	13.8	15.2
9	10	10	4	4	2	4			6	89	2	14	460	584	416	228	12.5	16.4	14.5	12.0	12.4	13.9	11.8	14.3
10	6	20	0	4	0	4			79	117	9	13	516	816	272	432	13.6	15.4	11.2	15.4	13.3	13.2	13.8	13.0
11	19	27	7	13	4	8			115	112	11	38	720	984	274	520	16.7	16.2	12.8	12.3	11.1	10.9	11.7	11.1
12	15	14	4	4	2	4			55	66	11	25	556	468	374	288	15.8	16.6	12.4	11.5	12.3	15.8	12.2	10.6
13	10	13	1	4	2	4			80	120	14	11	512	999	386	520	13.8	15.6	15.1	15.6	13.4	14.4	11.3	12.8
14	17	8	5	4	0	16			96	141	13	9	648	944	348	380	14.3	15.3	15.5	18.1	15.3	12.5	11.4	11.7
15	6	15	6	1	2	0			65	131	9	9	472	688	220	512	15.1	16.6	12.6	14.7	9.6	13.1	12.0	10.6
16	12	10	2	5	2	4			57	92	9	16	416	920	300	492	12.2	13.9	12.1	14.2	14.6	15.0	14.2	12.5
17	5	8	1	4	2	2			59	79	4	8	436	460	260	294	16.1	14.7	11.8	11.4	12.9	14.1	13.8	13.5
18	6	10	1	3	0	2			95	103	41	19	600	600	272	296	12.3	12.5	9.2	13.4	12.1	14.2	10.0	12.5
19	9	32	8	11	8	4			60	82	32	16	388	784	218	418	13.9	16.2	10.9	15.2	13.0	13.4	12.9	12.0
20	16	18	7	9	6	2			79	149	6	9	672	776	264	684	16.4	17.0	13.0	15.1	14.5	12.2	13.9	10.6
21	20	16	3	8	2	6			77	125	51	26	520	448	386	206	15.5	17.1	12.3	13.0	14.4	12.0	12.4	9.9
22	13	10	4	2	8	2			93	143	14	20	564	520	244	262	14.7	18.6	13.2	13.2	11.4	15.7	13.6	11.4
23	20	8	4	2	2	4			95	143	15	26	768	708	366	312	15.3	16.3	12.9	10.3	13.3	14.5	11.2	13.6
24	6	17	2	2	0	2			60	92	13	21	508	632	294	378	16.0	17.6	9.9	11.3	13.5	12.8	13.9	14.2
2567																								
1	11	19	12	22	8	10	2	6	67	202	10	29	492	968	342	460	20.5	20.2	16.0	14.0	16.5	16.4	15.2	12.0
2	6	12	7	5	4	2	0	4	81	83	10	36	460	796	208	324	25.5	24.9	13.6	17.2	15.3	16.3	15.3	18.2
3	4	21	8	18	2	20	2	26	95	160	19	17	600	1040	276	600	22.0	18.6	16.7	17.1	15.1	16.2	13.7	12.6
4	5	28	6	15	4	10	0	8	97	95	24	22	392	840	218	240	25.6	20.0	14.6	11.9	14.9	17.9	17.7	15.1
5	13	21	12	17	10	18	12	42	78	105	7	12	588	696	324	404	22.9	21.0	14.5	16.2	17.2	17.2	14.0	16.2
6	22	19	18	16	6	16	4	8	74	88	12	12	600	772	262	360	22.1	20.0	14.1	16.9	17.5	13.6	15.1	14.6
7	7	17	9	15	6	16	2	6	114	212	15	81	572	1000	384	384	21.7	22.3	17.5	13.3	17.0	16.1	12.5	13.2
8	8	26	22	18	6	10	4	10	100	150	15	15	744	896	264	444	24.0	23.1	14.0	16.8	16.5	16.7	14.9	15.5
9	5	15	12	13	4	6	2	4	83	95	5	15	672	584	468	220	20.4	21.3	21.2	16.7	15.9	10.9	13.6	15.1
10	6	31	4	21	2	14	2	8	83	170	19	19	572	1968	250	984	23.4	22.3	15.8	13.3	16.0	16.1	16.0	13.2
11	16	23	17	16	10	10	4	8	102	129	19	22	572	920	240	280	21.7	21.7	16.1	15.6	17.8	15.2	16.0	14.8
12	12	14	13	10	6	6	2	6	50	78	10	17	558	600	372	296	21.5	24.1	15.2	13.5	17.2	18.8	13.2	17.5
13	5	14	6	11	4	8	2	8	102	184	19	7	552	796	344	398	20.6	20.7	15.6	18.2	16.4	17.6	14.9	15.9
14	12	17	19	12	8	8	4	8	114	202	19	15	644	872	282	438	24.1	24.2	16.6	17.1	15.8	15.2	13.4	15.7
15	10	11	9	7	2	2	0	2	144	134	22	12	772	800	260	342	22.4	21.2	16.1	14.5	17.0	16.3	14.1	15.4
16	10	16	4	14	6	8	2	12	69	100	29	12	660	952	114	556	15.8	20.6	16.7	14.9	16.9	20.2	16.0	16.1
17	9	13	7	10	2	4	0	4	129	105	15	5	504	512	212	290	23.7	19.3	15.5	13.0	15.8	16.5	17.0	16.9
18	7	8	6	11	4	2	0	4	160	202	31	10	724	772	324	264	17.8	19.3	13.9	15.8	17.2	21.5	17.8	14.2
19	13	25	10	22	18	22	8	18	74	90	36	10	522	840	162	448	20.5	22.8	11.5	15.2	14.8	18.1	15.4	16.8
20	9	11	17	18	32	18	8	8	105	194	15	31	756	984	344	396	26.3	22.9	15.7	13.2	14.9	15.9	9.0	10.9
21	8	13	12	16	28	18	12	12	116	170	15	36	592	548	332	256	22.7	23.2	15.1	13.2	16.7	18.0	15.5	14.9
22	6	15	11	15	8	14	6	4	124	170	19	50	498	800	248	294	19.3	25.9	14.8	19.5	15.6	16.4	15.2	13.5
23	12	10	14	14	4	16	0	6	64	76	12	22	600	544	324	220	22.5	22.6	17.1	14.3	18.2	14.5	15.1	14.9
24	10	6	12	3	4	2	2	0	105	83	26	45	600	800	172	374	21.1	22.3	8.5	11.4	15.7	15.4	16.8	16.3

APPENDIX C. REGRESSION EQUATIONS WITH SIX VARIABLES FOR SEVENTEEN SITE-YEARS, REGRESSION COEFFICIENTS (b_{ij})[a], COEFFICIENTS OF DETERMINATION (R^2) AND MEAN YIELDS, QUINTALS PER HECTARE

SITE-YEAR	variable and regression coefficient							R^2	Mean yield q/ha
	Intercept b_0	N_A b_1	P_A b_2	N_A^2 b_{11}	P_A^2 b_{22}	$N_A \cdot P_A$ b_{12}	Replicate b_5		
0164	13.22902	0.00393	0.34890**	-0.00009	-0.00346**	0.00025	-2.38915**	0.797	17.5
0165	20.54070	0.13677**	0.38267**	-0.00088**	-0.00619**	0.00009	-1.69000	0.644	26.2
0167	13.45241	0.11840**	0.39226**	-0.00076**	-0.00567**	0.00055	-1.74541*	0.789	20.3
0365	13.33406	0.13735**	0.20010*	-0.00098**	-0.00331*	0.00187**	0.34458	0.823	20.8
0367	9.94862	-0.00630	0.35606**	-0.00003	-0.00517**	0.00048	-0.78374	0.692	13.5
0565	14.13231	0.31964**	0.18676	-0.00165**	-0.00236	-0.00054	-2.48750*	0.758	24.0
0566	11.44587	0.13990**	0.16874	-0.00086**	-0.00318*	0.00093**	-0.76125	0.708	17.0
0567	15.39030	0.17726**	0.15870*	-0.00075**	-0.00246*	0.00047	-0.42958	0.875	23.9
2164	20.16624	0.02904	0.13541	-0.00032	-0.00217	0.00029	1.49500	0.288	22.4
2165	23.56566	0.10214*	0.33393*	-0.00058	-0.00394	-0.00102	-3.26792**	0.432	27.4
2166	29.17310	0.10417	-0.36296*	-0.00075	0.00416	0.000124	5.85250	0.397	31.0
2167	20.17578	0.15679**	0.07573	-0.00108**	-0.00100	-0.00016	-0.21417	0.423	23.7
2366	11.06335	0.09477*	0.14309	-0.00019	-0.00272	-0.00036	-2.66583**	0.649	14.8
2367	19.67302	0.07858*	0.39057**	-0.00049	-0.00672**	0.00092*	0.43874	0.692	26.3
2565	11.60530	0.32117**	-0.00425	-0.00099*	-0.00033	0.00044	3.39873*	0.819	27.8
2566	12.12226	0.19504**	-0.01572	-0.00091**	-0.00086	0.00083*	0.55208	0.765	19.1
2567	16.92856	0.32492**	0.17995	-0.00182**	-0.00482*	0.00070	2.73332*	0.782	28.0

[a] Levels of significance are: **: 0.01
*: 0.05

APPENDIX D. REGRESSION EQUATIONS WITH FIFTEEN VARIABLES FOR SEVENTEEN SITE-YEARS, REGRESSION COEFFICIENTS (c_{ij})[a] COEFFICIENTS OF DETERMINATION (R^2) AND MEAN YIELDS, QUINTALS PER HECTARE

SITE-YEAR	variable and regression coefficient[b]								
	Intercept	N_A	P_A	N_S	P_S	N_A^2	P_A^2	N_S^2	P_S^2
	c_0	c_1	c_2	c_3	c_4	c_{11}	c_{22}	c_{33}	c_{44}
0164	21.93188	-0.01425	0.42709**	-0.10864	-0.57157	-0.00015	-0.00351*	0.00015	-0.01464
0165	18.45184	0.09017	0.29885	0.08677	-0.07933	-0.00051	-0.00662*	-0.00007	-0.01055
0167	15.18010	0.14088*	0.37301*	-0.04033	-0.13346	-0.00081*	-0.00612	0.00012	-0.00110
0365	11.60880	0.15559**	0.19591*	0.01029	0.61078	-0.00092**	-0.00315	-0.00670	-0.02960
0367	8.73092	-0.00815	0.39571**	0.01360	0.01659	-0.00018	-0.00503*	-0.00030	0.00063
0565	4.93385	0.51424**	-0.19369	0.05044	0.75641	-0.00193**	-0.00051	0.00411	-0.01547
0566	15.50459	0.18662**	0.19580	-0.14608	-0.32226	-0.00099**	-0.00435*	-0.00077	-0.00214
0567	21.06871	0.23632	0.02038	-0.32743*	0.01263	-0.00062**	-0.00322	0.00469*	-0.00356*
2164	16.71013	0.04779	-0.16250	0.12145	-0.07620	-0.00056*	-0.00148	-0.00036*	-0.00098
2165	38.90746	0.03218	0.36468	-0.04195	-0.38525	-0.00049	-0.00330	0.00006	0.00227
2166	22.31294	0.19556	-0.19643	-0.01003	-0.02329	0.00042	-0.00075	0.00097	-0.00149
2167	24.17961	0.16870**	0.07492	-0.04204	-0.04644	-0.00106**	-0.00098	0.00022	0.00028
2366	10.70090	0.09890	0.20321	0.00751	0.02227	-0.00000	-0.00214	-0.00281	0.00028
2367	14.06096	0.08572	0.65198	0.12577	-0.01937	-0.00067	-0.00488	-0.00659	-0.00057
2565	-3.79574	0.41925**	0.01425	0.33947	0.09737	-0.00117*	0.00329	-0.00152	-0.00057
2566	8.52378	0.31756**	-0.03733	-0.29939	0.07480	-0.00069	-0.00060	0.00720	-0.00047
2567	32.27734	0.33260**	0.35585	-0.12697	-0.25200*	-0.00164**	-0.00475	0.00209	0.00064

[a] Levels of significance are: **: 0.01
*: 0.05

[b] Units are kilogram/hectare for soil and applied nutrient levels.

APPENDIX D. (continued)

SITE-YEAR	variable and regression coefficient[b]							R^2	Mean yield q/ha
	$N_A \cdot P_A$	$N_A \cdot N_S$	$N_A \cdot P_S$	$P_A \cdot N_S$	$P_A \cdot P_S$	$N_S \cdot P_S$	Replicate		
	c_{12}	c_{13}	c_{14}	c_{23}	c_{24}	c_{34}	c_5		
0164	0.00035	0.00016	0.00132	-0.00041	-0.00565	0.00796	-2.76585**	0.818	17.5
0165	-0.00138	-0.00072	0.00337	0.00009	0.00874	0.00072	-0.36798	0.783	26.2
0167	-0.00018	-0.00011	0.00034	0.00083	0.00316	0.00119	-1.55922	0.804	20.3
0365	0.00157**	0.00035	-0.00277	-0.00330	0.00580	0.00768	-0.54086	0.890	20.8
0367	0.00113	0.00041	-0.00123	-0.00104	-0.00153	0.00164	-0.89632	0.711	13.5
0565	-0.00017	-0.00284	-0.00376	-0.00338	0.01324*	-0.00446	-2.85052*	0.837	24.0
0566	0.00173*	0.00037	-0.00288	-0.00549	0.00618	0.01492	-0.98420	0.768	17.0
0567	-0.00012	-0.00199	0.00010	0.00238	0.00527	0.00163	-1.09389	0.913	23.9
2164	0.00108**	0.00013	-0.00091	0.00016	0.00410*	0.00013	1.67762*	0.629	22.4
2165	-0.00167	-0.00000	0.00129	-0.00002	-0.00049	0.00039	-4.06408**	0.509	27.4
2166	0.00111	-0.00271	-0.00003	-0.00195	0.00433	0.00158	5.31463**	0.493	31.0
2167	-0.00071	-0.00014	0.00017	0.00058	-0.00015	-0.00025	-0.65830	0.477	23.7
2366	-0.00101	-0.00017	0.00003	0.00312	-0.00269	0.00035	-2.65653**	0.751	14.8
2367	0.00134	0.00072	-0.00019	-0.00840	-0.00138	0.00581	1.39743	0.747	26.3
2565	0.00072	-0.00208	-0.00027	-0.00395	-0.00162	0.00246	2.78665	0.880	27.8
2566	0.00065	-0.00398	-0.00044	-0.00043	0.00024	0.00204	0.45096	0.806	19.1
2567	0.00104	-0.00114	0.00007	-0.00371	-0.00012	0.00117	2.53279	0.836	28.0

APPENDIX E. APPARENT DENSITIES AND MOISTURE CHARACTERISTICS OF SOILS FOR EXPERIMENTAL SITES 1959 - 1963

				moisture per cent			available water, in.	
SITE-YEAR	hor-izon	depth[a] in.	d g/cm^3	when sown	1/3 atm	15 atm	1/3 atm	when sown
0160	Ap	0- 7	1.32	22.0	15.8	7.5	0.77	1.34
	B	7-21	1.58	18.0	14.9	8.7	1.37	2.06
	C	21-36	1.54	12.0	11.4	7.2	0.97	1.11
0259	Ap	0- 5	1.20	32.0	37.9	19.2	1.12	0.77
	B	5-19	1.52	22.0	32.9	18.1	3.15	0.83
	C	19-36	1.56	28.0	32.6	13.6	5.04	3.82
0260	Ap	0- 4	1.20	43.0	35.9	19.0	0.81	1.15
	B	4-19	1.54	26.0	31.6	15.6	3.70	2.40
	C	19-36	1.42	30.0	38.0	14.3	5.72	3.79
0359	Ap,Ae	0- 8	1.25	23.0	30.4	14.0	1.64	0.90
	Bg	8-22	1.64	18.0	22.0	11.6	2.39	1.47
	Cg	22-36	1.78	17.0	22.6	11.6	2.74	1.37
0360	Ap,AB	0-11	1.40	29.0	23.7	10.4	2.05	4.40
	B	11-22	1.66	19.0	21.8	11.2	1.94	1.42
	C	22-36	1.80	17.0	23.1	11.5	2.92	1.39
0361	Ap	0- 7	1.26	25.6	27.0	12.3	1.30	1.25
	AB,B	7-19	1.74	17.0	25.1	12.4	2.65	0.96
	C	19-36	1.64	18.8	21.8	10.6	3.12	2.29
0460	Ah	0- 9	1.13	25.4	32.5	16.2	1.66	0.94
	Bg	9-24	1.46	13.8	26.7	12.9	3.02	0.20
	Ckg	24-36	1.45	19.9	33.4	15.4	3.13	0.78
0560	A	0- 6	1.18	26.0	28.6	12.1	1.17	0.98
	AB	6-18	1.28	14.0	26.2	10.6	2.40	0.52
	B	18-36	1.36	20.0	33.3	14.0	4.72	1.47
0561	A	0-10	1.32	16.7	27.8	10.8	2.24	0.78
	B	10-30	1.51	16.7	28.7	13.2	4.68	1.06
	C	30-36	1.39	16.2	33.7	12.4	1.78	0.32
0562	A	0-10	1.24	25.7	25.8	10.8	1.86	1.85
	AB,B	10-22	1.46	21.2	25.4	10.9	2.54	1.80
	B	22-36	1.46	17.4	29.8	12.7	3.50	0.96

[a] Observations not converted to metric equivalents as required in scale shown for input in soil moisture budget equation.

APPENDIX E. (continued)

SITE-YEAR	hor-izon	depth[a] in.	d g/cm^3	moisture per cent			available water, in.	
				when sown	1/3 atm	15 atm	1/3 atm	when sown
0563	A	0- 7	1.41	21.1	27.0	10.2	1.66	1.08
	B	7-23	1.56	16.6	31.5	14.9	3.72	0.42
	C	23-36	1.28	15.6	34.7	11.6	3.84	0.67
0661	Ap,Ae	0- 9	1.26	20.4	32.7	10.3	2.54	1.15
	B	9-31	1.49	18.3	33.9	14.5	6.36	1.25
	C	31-36	1.39	17.0	39.0	14.2	1.72	0.19
0761	A	0- 9	1.38	17.8	20.9	8.0	1.60	1.22
	B	9-22	1.54	15.0	18.9	9.2	1.94	0.72
	C	22-36	1.53	9.4	14.4	6.1	1.78	0.71
0762	A	0- 8	1.41	26.2	19.4	7.8	1.31	2.08
	B	8-24	1.66	14.0	13.9	7.3	1.75	1.78
	C	24-36	1.54	9.2	17.1	7.0	1.87	0.41
0763	A	0- 8	1.39	12.0	18.3	6.1	1.36	0.66
	B	8-24	1.77	11.0	18.4	9.4	3.19	0.57
	C	24-36	1.80	11.0	19.4	9.5	1.43	0.22
0861	A	0-12	1.26	22.9	24.3	9.8	2.19	1.98
	B	12-24	1.40	18.8	24.6	8.6	2.69	1.71
	C	24-36	1.47	18.4	27.2	9.8	3.07	1.52
0862	A	0-10	1.26	20.6	22.2	7.6	1.84	1.64
	B	10-21	1.48	15.7	24.0	9.4	2.38	1.03
	C	21-36	1.48	14.9	25.6	9.9	3.49	1.11
0863	A	0-10	1.26	17.8	23.0	9.3	1.70	1.07
	B	10-19	1.38	13.8	22.0	9.1	1.60	0.58
	C	19-36	1.52	11.2	26.1	9.9	4.19	0.34
0961	A	0-12	1.28	27.5	27.2	12.8	2.21	2.24
	B	12-29	1.51	20.6	27.8	16.2	2.75	1.04
	C	29-36	1.41	18.9	28.4	12.5	1.57	0.63
0962	A	0-13	1.38	30.9	22.5	13.0	1.80	3.21
	B	13-25	1.60	17.4	20.8	10.2	2.04	1.38
	C	25-36	1.63	20.0	25.3	11.7	2.44	1.49

APPENDIX E. (continued)

SITE-YEAR	horizon	depth[a] in.	d g/cm^3	moisture per cent when sown	moisture per cent 1/3 atm	moisture per cent 15 atm	available water, in. 1/3 atm	available water, in. when sown
0963	A	0-10	1.31	18.4	23.2	9.7	1.77	1.14
	B	10-26	1.61	15.0	20.9	11.3	2.47	0.95
	C	26-36	1.63	13.4	24.0	11.6	2.02	0.29
1061	A	0-12	1.25	27.6	32.7	14.2	2.78	2.01
	B	12-31	1.37	21.8	31.6	15.6	4.16	2.21
	C	31-36	1.46	23.0	35.6	13.7	1.60	0.68
1062	A	0-12	1.22	33.5	32.4	16.0	2.40	2.56
	B	12-30	1.44	21.7	30.8	15.3	4.02	1.66
	C	30-36	1.40	23.4	34.2	13.2	1.76	0.86
1063	A	0-12	1.18	25.0	36.0	16.4	2.78	1.22
	B	12-29	1.48	22.3	31.6	15.0	4.18	1.03
	C	29-36	1.46	26.4	37.1	13.9	2.37	1.28
1162	Ap	0- 5	1.38	22.9	24.6	9.8	1.02	0.90
	B	5-20	1.52	19.0	28.6	14.2	3.28	1.09
	B	20-36	1.56	18.8	31.0	15.5	3.87	0.82
1163	Ap,Ae	0- 8	1.34	20.1	22.0	8.4	1.46	1.25
	B	8-19	1.49	15.5	15.8	7.6	1.34	1.29
	B	19-32	1.38	20.4	33.6	14.1	3.50	1.13
1262	Ap,Ae	0-12	1.39	24.3	23.2	8.0	2.54	2.72
	B	12-28	1.55	20.0	29.1	14.6	3.60	1.34
	C	28-36	1.51	18.8	29.7	12.2	2.11	0.80

APPENDIX F

NOTES ON CALCULATING POTENTIAL EVAPORATION BY THE PENMAN EQUATION

Introduction

A large number of rather complex computations are encountered in using the Penman equation to estimate daily potential evaporation. A computer programme[6] written in FORTRAN IVH was devised for these computations and used on an IBM 360/67. These notes describe methods used to compute the terms in the general Penman equation.

The programme uses basic equations to calculate vapour pressure relationships from psychrometric observations. There are two restrictions to the direct application of the computer programme:

(a) Calculations are limited to 153 days of the year, May 1 to September 30, inclusive.

(b) A listing of maximum hours of bright sunshine is used which is appropriate to latitude 54.

Penman equation

The Penman equation and modifications to meet particular situations of the evaporation surface were reviewed by Penman (1963).

[6] Available from the Department of Soil Science, University of Alberta.

The general equation is of the form:

$$E = \frac{\frac{\Delta}{\gamma}H + E_a}{\frac{\Delta}{\gamma} + 1}$$

where E is potential evaporation, H is the heat budget, E_a is an expression for the "drying-power" of the atmosphere and the ratio $\frac{\Delta}{\gamma}$ is a weighting factor. Each of these terms will be discussed, but it is convenient to first describe calculations of vapour pressure relationships.

Psychrometric computations

Psychrometric observations are used to determine saturation (e_a) and actual (e_d) vapour pressures (mm Hg) of the atmosphere. The programme accepts sets of observations recorded in one of three forms:

(a) dry- and wet-bulb temperatures (2 sets daily),

(b) dry-bulb and dew-point temperatures (2 sets daily) or

(c) air temperature and relative humidity (4 sets daily).

Saturation vapour pressure of the atmosphere

The equations of Goff and Gratch (1946) are used to compute e_a. These equations are stated and discussed by List (1968) in the Smithsonian Meteorological Tables (p. 350). It is noted that:

(a) Two equations are presented, describing the condition over water (e_w) and over ice (e_i), expressed in mb.

(b) The equation for e_i is called in the programme only when dry-bulb temperature is less than 32 F.

(c) Two errors in stating the equation for e_w were corrected in the 1968 reprint of the Smithsonian Meteorological Tables.

(d) A linear correction is applied for actual air pressure. As discussed by Harrison (1965a), moist air does not exactly fulfill relationships that express the ideal gas law. However, at an air pressure of 935 mb (Edmonton average pressure) the assumption of ideality results in an error of less than 0.4 per cent in computing e_a.

Actual vapour pressure of the atmosphere

The method for computing e_d depends on the form in which the psychrometric data has been recorded:

(a) Dry- and wet-bulb temperatures require the psychrometric equations presented by List (1968, p. 366) to calculate e_d.

(b) Dew-point temperature, T_d, of moist air at temperature T, is the temperature to which the air must be cooled in order that it shall be saturated with respect to water. Thus, e_d is calculated as e_a at temperature T_d, using equations presented by List (1968, p. 350).

(c) Air temperature and relative humidity (RH) require the calculation of e_a, then e_d can be calculated:

$$e_d = e_a \times RH/100$$

Delta (Δ)

The Δ term in the Penman equation is the slope of the saturation vapour pressure curve at temperature T. A printing error occurs in the formula presented by List (1968, p. 372) for calculating Δ:

$$174209 \times 10 - \frac{1302.88}{T} \quad \text{should read:} \quad 174209 \times 10^{\frac{-1302.88}{T}} .$$

Psychrometric constant (γ)

A value of 0.65 mb/°C is assumed for the so-called psychrometric constant. Calculations based on data presented by List (1968, p. 365) and Harrison (1965b) reveal that this assumed value of γ is without error at a wet-bulb temperature of 45 F and the actual error would seldom exceed 1 per cent.

Heat budget (H)

The heat budget can be divided into its component parts by the relationship:

$$H = (1-r)R_I - R_B$$

where r is the albedo (reflection coefficient), R_I is incoming short-wave radiation and R_B is net outward long-wave radiation. This relationship neglects horizontal gradients of temperature and humidity, an

ideal situation where the site of meteorological observations is indistinguishable from the surrounding macroenvironment (this larger area being of the order of 10^5 m^2). A more complete treatment of aspects of the heat budget has been given by Penman (1963), Sellers (1965) and Slatyer (1967).

Albedo (r)

Surface albedo, the portion of incident solar radiation that is reflected from the ground, is principally a function of the angle of incidence of the solar radiation and the nature and condition of the reflecting surface. Since R_B is not a negligible quantity relative to R_I, the estimation of H is rather sensitive to the value assigned r.

In estimating the heat budget over annual crops the problem arises that the albedo of the bare soil may differ markedly from that when a complete ground cover is achieved. An option is provided in the computer programme permitting an initial albedo to be assigned relevant to the colour and condition of the soil surface after seeding of the crop. This option requires that the date of crop emergence be designated. The initial albedo is used in calculations of the daily heat budget until crop emergence, thereafter the albedo changes slowly until the albedo is appropriate to a complete ground cover.

The albedos used to estimate potential evaporation in this study were not obtained by direct observation, but were estimates based on data presented by Bowers and Hanks (1965), van Wijk (1966) and Ioffe and Revut (1959).

Incoming short-wave radiation (R_I)

In this study, observations of R_I made with an Eppley pyrheliometer at Stony Plain (near Edmonton) were used in calculating daily heat budgets for all experimental sites.

Penman (1963, p. 41) presented a formula for estimating R_I,

$$R_I = R_A(0.18 + 0.55\ n/N),$$

where R_A is the theoretical maximum solar radiation that could reach the site in the absence of the earth's atmosphere and n/N is the ratio of actual to possible hours of bright sunshine. This formula takes into account the amount of cloud cover, but not the type of cloudiness.

Net outward long-wave radiation (R_B)

In the computer programme a formula presented by Penman (1963, p. 41) is used to estimate daily R_B,

$$R_B = \sigma T^4(0.56 - 0.09\ e_d^{\frac{1}{2}})(0.10 + 0.90\ n/N),$$

where e_d is actual vapour pressure of the air, n/N is the ratio of actual to possible hours of bright sunshine, T is mean air temperature (°K) and σ is the Stefan-Boltzmann constant (= 1.98×10^{-9} mm H_2O/cm^2/day/$°K^4$).

It is noted that regional observations of R_B were available but, since instruments for long-wave radiometry are generally unreliable, it was decided that a calculated value of R_B would be more suitable for estimating the heat budget.

Drying-power of the atmosphere (E_a)

The equation of the drying-power of the atmosphere, appropriate to a crop surface, was presented by Penman (1963, p. 42):

$$E_a = 0.35(1 - u/100)(e_a - e_d),$$

where u is wind speed (miles/day) at a height of 200 cm. The terms e_a and e_d have been described.

A sub-routine in the computer programme permits estimation of u from wind observations are made at heights other than 200 cm. The relationship expressed by the power law is used:

$$u_1/u_2 = (z_1/z_2)^p ,$$

where u_1 is wind speed at height z_1, u_2 is wind speed at height z_2 and p is a variable depending upon the stability of the air layer. Based on evidence presented by Sutton (1960) and Sellers (1965), a value of 0.20 was chosen for this exponent. It is noted that while values of p given in the literature range from near zero to 0.85, the value 0.20 is compatible with evidence obtained at heights from 2 to 15 meters at wind speeds in the moderate range.